T H E S I S

PRESENTED to the UNIVERSITY of EDINBURGH for the

DEGREE of PH.D.

on

THE SCATTERING of X-RAYS

An ACCOUNT of INVESTIGATIONS into the J-PHENOMENA

in the SCATTERING of X-RADIATION

showing -

(a) The apparent development of the J-discontinuities on prolonged exposure of the scattering material.

(b) Discontinuities in the Absorption of the X-Radiations Transmitted and Scattered by Substances.

BY

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The research, of which this thesis contains an account, was carried out in the Physical Laboratory of the University of Edinburgh, under the supervision of Professor C. G. BARKLA, F.R.S., whom the author has to thank for the use of the apparatus which was placed at his disposal during the course of the investigations, which extended over the period from November 1928 to March 1932.

INTRODUCTION.

According to the Classical theory of radiation, if a beam of monochromatic X-Radiation is allowed to fall on a material medium, the extranuclear electrons of the atoms of the medium will be set into forced vibration and will become new sources of X-radiation. This forced vibration should have a frequency exactly equal to the frequency of the incident vibration, or radiation, producing it. Any vibrating electron will thus emit, or scatter, X-radiation in all directions, the frequency of the scattered rays being the same in all directions and equal to that of the incident radiation. The intensity of the scattered radiation is not the same in all directions, being a maximum along the direction of the incident radiation and a minimum in a direction at right angles to the direction of the incident radiation.

*COMPTON, however, when experimenting on scattered radiations produced in this way, observed that the scattered radiation was not of the same frequency as the incident radiation, but that its wave/

* Phys. Rev. May 1923

wave length was longer than that of the incident. *ROSS, using a photographic method instead of the electro-metric method used by COMPTON, made a similar observation, noticing, in addition, that the scattered radiation contained not monochromatic radiation, like the incident radiation, but radiation of two different wavelengths. One of these radiations had exactly the wavelength of the incident radiation, while the other had a wavelength greater than that of the incident by an amount ·025Å. COMPTON had observed a difference of ·022Å between the wavelengths of the incident and the scattered radiations. The radiations used by these experimenters was the Molybdenum Kα radiation, scattered, in COMPTON'S experiments, from graphite, and in ROSS'S experiments from calcite, the direction of the scattered radiation being at 90° to the incident radiation, COMPTON and DEBYE showed that this increase in wavelength could be accounted for, on the quantum theory of radiation, by taking into account the principles of conservation of energy and momentum. By this reasoning, if X-radiation of frequency ν falls on an electron and causes the electron to be ejected from the atom, the electron scatters X-radiation in a given direction/

* Proc. Nat. Acad., July 1923.

direction, but that is not all. The frequency of the radiation scattered in a direction making an angle θ with the direction of the incident radiation of frequency ν depends on the angle θ through which it is scattered. In terms of wavelengths of the radiations concerned, this means that the wavelength of the X-radiation scattered in a direction making an angle θ with the incident radiation of wavelength λ, is greater than the wavelength of the incident radiation, by an amount -

$$\delta\lambda = \frac{h}{mc}(1-\cos\theta)$$

where h = Planck's constant
m = mass of scattering electron
and c = velocity of electromagnetic radiations.

When $\theta=90°$, as in the experiments of COMPTON and ROSS, the increase $\delta\lambda$ becomes ·0242Å, a value agreeing with the values observed by these experimenters.

The experiments have been repeated many times, using both photographic methods and ionisation methods. The photographic results show that the scattered radiation is not monochromatic, but consists of radiation of two wavelengths, one radiation having the same wavelength as the incident radiation, the other having a wavelength greater than/

than that of the incident by an amount approximately ·0242Å as given above. Absorption methods have given varying results. Some experiments using this method, give results agreeing with the "change of wavelength on scattering" theory, others show results which do not. The 'modified' radiation is not always evident in absorption experiments.

This is particularly true of the results of experiments which have been carried out over a long period of years in the Physical Laboratory of the University of Edinburgh. In these experiments, the incident radiation was not monochromatic or homogeneous, as in the experiments of COMPTON and ROSS, but panchromatic or heterogeneous. The results of such experiments as have been made in this Laboratory are of two kinds; those in which the scattered radiation is of the same absorbability as the incident, and those in which it has an absorbability different [redacted] from that of the incident; i.e. those in which its average wavelength seems to have increased as required by the COMPTON theory of scattering. Of these experiments more will be written later.

According to the COMPTON-DEBYE theory of scattering, each scattering electron emits radiation/

radiation in a given direction. If the incident beam is homogeneous and of wavelength λ, the radiation scattered in a direction making an angle θ with the incident radiation will be of wavelength $[\lambda + \cdot 0242(1-\cos\theta)]$Å. Thus the scattered radiation will be absorbed more easily than the incident radiation by any material on which it is incident. In the same way, according to current ideas, each constituent radiation in the heterogeneous radiation incident on a material medium should produce, to a certain degree, scattered radiation of a wavelength longer than the wavelength of the constituent producing it. Thus the scattered radiation will be heterogeneous and of a quality slightly different from that of the incident radiation. The absorbability of the scattered radiation will, most probably, be different from that of the incident. It is this difference in absorbability which is tested in the experiments carried out in this Laboratory.

If a beam of X-radiation, whether homogeneous or heterogeneous, is passed into a gold-leaf electroscope, the charge on the leaf is lost due to the attraction, by the charged leaf, of ions produced by the radiation in the air of the electroscope. The number/

number of ions produced in the space per second, by a given type of radiation, will depend on the intensity of the beam of radiation. The greater the intensity, for a given type of radiation, the greater the number of ions produced and, consequently, the greater the rate of loss of charge from the gold-leaf. If absorbing material be introduced into the path of the radiation before it reaches the electroscope, the intensity will be diminished due to the absorption of radiation by the material, the absorption being due to the fact that the energy necessary to cause emission of electrons from the material must be obtained from the energy of the beam of X-rays. Thus the transmitted radiation will produce a smaller number of ions per second in the electroscope, so that the rate of loss of charge from the gold-leaf will be smaller than when the beam was unintercepted. A beam of high frequency is less absorbed by a given sheet of material than a beam of low frequency. The incident radiation falling on, and transmitted through a medium, will be of higher frequency, (i.e. of shorter wavelength) than a beam scattered through an angle θ, if the COMPTON-DEBYE theory is correct. Thus, if we pass the transmitted beam and the scattered beam through equal thicknesses of the same material/

material, the diminution of intensity of the transmitted beam should generally be different from the corresponding decrease in the intensity of the scattered radiation, so that, if the beams are received into separate electroscopes, and the ionisation loss of charge from the gold leaf of each in a given time is measured first when the beams are not intercepted by any material and again when they are made to pass through equal thicknesses of the same absorber before reaching the scatterer, it should be observed that the ratio -

$$\frac{\text{ionisation loss of charge from leaf of electroscope receiving scattered rays.}}{\text{ionisation loss of charge from leaf of electroscope receiving transmitted rays.}}$$

varies steadily as the equal thicknesses of absorbing material in each beam are increased. The ionisation loss of charge can be measured most conveniently by observing the change in the deflection of the charged gold-leaf.

On the other hand, if the Classical theory is the correct one, it should be found that the ratio above remains constant for all thicknesses of absorbing material placed in each beam. This is evident from the fact that there is no change in wavelength/

wavelength on scattering and that every constituent is scattered in the same proportion, so that the scattered radiation should have the same absorbability as the transmitted. Experiments, dealing with the behaviour of the above ratio as the equal thicknesses of the intercepting material in each beam are increased, are known as "filtering experiments".

Again, since the COMPTON-DEBYE theory shows that the change of wave-length, experienced on scattering, is independent of the wavelength of the radiation scattered, a beam of homogeneous X-radiation scattered through an angle θ from a beam of very short wavelength will suffer a relatively greater change in wavelength than a beam of long wavelength scattered through the same angle, i.e. the increase in "ionising power"* of the former will be greater than the increase in "ionising power" of the latter. Thus the ratio -

$$\frac{\text{number of ions produced in the electroscope receiving scattered rays.}}{\text{number of ions produced in the electroscope receiving transmitted rays.}}$$

will be greater for the incident radiation of very short wavelength. Hence, if the wavelength of the incident/

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* By "ionising power" the writer means a measure of the number of ions produced by the radiation per second in a given volume of a given gas.

radiation is increased, the ratio -

$$\frac{\text{deflection of gold leaf in electroscope receiving scattered rays.}}{\text{deflection of gold leaf in electroscope receiving transmitted rays.}}$$

should decrease with increase of wavelength. If a heterogeneous beam is used than each constituent will be increased in wavelength on scattering and the scattered radiation will be of such a nature that the last-mentioned ratio will, in general, vary with the average wavelength of the incident beam. On the other hand, if the Classical theory is correct, the ratio should remain constant, because there is no change of wavelength on scattering and each constituent is scattered in the same proportion and therefore the scattered and incident beams have exactly the same "ionising power" (except for intensity) since they are equally absorbable.

Experimental investigation of relative absorbabilities of the scattered and transmitted radiations, either

(a) by hardening the incident radiation gradually

or (b) by keeping a fixed incident radiation and filtering each beam.

will show whether the COMPTON-DEBYE theory or the Classical/

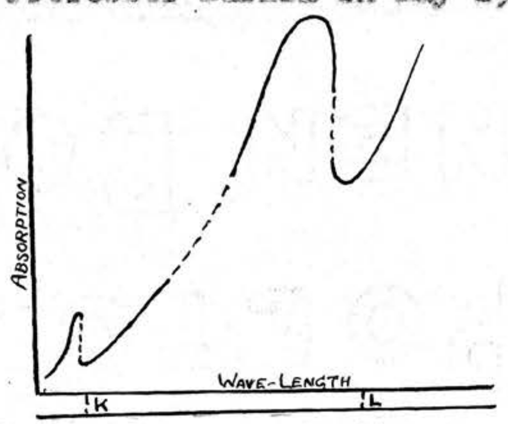
Classical theory is sufficient to explain the observed facts of scattering.

As mentioned above, the production of the scattered radiation requires the intensity of the incident beam of radiation to be reduced. This is necessary on either theory.

So far, it has been assumed that X-radiation incident on matter produces only such scattered radiations as are required by the COMPTON theory or by the Classical theory. Substances exposed to X-radiation of a sufficiently short wavelength emit radiations characteristic of the elements of which they are composed. These characteristic radiations are accompanied by a corpuscular radiation due to the ejection, by the incident radiation, of electrons from the different energy levels of the Bohr atom. This characteristic radiation is superposed on the ordinary scattered radiation, but is produced only when the frequency of incident radiation is greater than the frequency of the characteristic radiation or, for a heterogeneous beam, when the incident beam contains a constituent radiation whose frequency is greater than that of the characteristic radiation produced. This is an extension of Stokes' Law in Optics, enunciated by BARKLA in the Jahrbuch der Radioaktivität und Elektronik, April, 1908.

When this characteristic radiation is omitted/

omitted by the substance, the intensity of the incident beam is reduced to a greater extent than normally, i.e. the amount by which the intensity of the incident beam is reduced suddenly increases when the characteristic radiation is produced, i.e. the absorption of the incident beam suddenly increases at this apoint, as can be observed from the following curve in which the wavelength of the primary or incident radiation is plotted against the absorption of the primary beam in the material used. The curve is reproduced from the Bakerian Lecture, delivered by Professor Barkla in May 1916.



It was shown on further experiment that there are for any given substance, a number of possible characteristic radiations, these radiations belonging to different groups which differ considerably in the frequency of their constituent radiations. Thus gold is observed to emit the following characteristic/

characteristic radiations:-

.152Å, 1.038Å, .899Å, and .860Å.

The first is the K - characteristic radiation, the others are the radiations of the L series of characteristic radiations from gold. It will be observed that the last three can be included in one group, their wavelengths only differing by small amounts.

The production of these characteristic radiations in the elements can be explained by introducing, into the BOHR conception of the atom, the idea of levels of energy for the extra-nuclear electrons. Thus a theory can be built up to account for the emission of the K, L, M, N, etc. groups of characteristic radiations. This theory does not permit of the emission, by an element, of a radiation of frequency greater than that of the K-radiation of shortest wavelength. Continuing his researches, BARKLA found indirect evidence of a characteristic radiation of a higher frequency than that of the K-radiation. To this he gave the name of the J-radiation. Further experiment has confirmed the original observation, but the phenomenon, in many of its features, appears to be a new one. Research now seeks to find the condition essential to the appearance of what is now called the J-phenomena in the scattering of/

of X-radiation.

This research has continued these earlier experiments of which an account follows.

TERMS USED IN THE DISCUSSION.

Before proceeding to an account of the work which has been done on the subject of the J-phenomena in X-rays, it will be necessary to outline the meaning of the symbols and terms used to describe experiments and results.

A beam of homogeneous X-radiation is completely described as regards frequency if its "absorption coefficient" is given. It has already been stated that the intensity of a beam of X-radiation is reduced when it passes through matter. Thus a beam of initial intensity I_0 is reduced to intensity I_x after passing through x cms. of a material placed in its path, the reduction in intensity being governed by the relation $I_x = I_0 e^{-\mu x}$ where the quantity μ thus introduced is defined as the absorption coefficient of the radiation. It will be obvious that/

that the transmitted beam will be of the same quality as the incident beam and, therefore, the absorption of the transmitted beam will be governed by the same equation.

A heterogeneous beam cannot be spoken about in this way, because each constituent has an absorption coefficient of its own, and the beam transmitted through the material is slightly different, as regards constitution, from the incident radiation. A similar method may be used to give a measure of what may be called the "average" absorption coefficient of the beam. If sufficient material is placed in the beam to reduce the intensity of the transmitted radiation to one-half the intensity of the incident, the average absorption coefficient can be calculated from the equation $I_x = I_0 e^{-\mu x}$. The 50% diminution of intensity is used in order to reduce errors which may arise, due to the heterogeneous nature of the beam. It will be seen that the "average absorption coefficient" thus obtained does not determine the "quality" of the beam because it will be obvious that a beam of average absorption coefficient u can be constituted in a number of ways from/

from different homogeneous radiations; the smaller the absorption coefficient of a beam, the greater its "hardness or penetrating power, if the beam is homogeneous. (For heterogeneous beams, the word average must always be introduced). A soft beam is one of large absorption coefficient or small penetrating power.

Sometimes, instead of the average absorption coefficient μ of a beam, it is more useful to use the mass-absorption coefficient of the beam in a given substance. Thus, if the equation of absorption be written, $I_x = I_0 e^{-(\frac{\mu}{\rho})\rho x}$ where ρ is the density of the material used to absorb the radiation, the quantity $(\frac{\mu}{\rho})$ is termed the mass-absorption coefficient of the rays. Usually to completely specify the measurement, the chemical symbol of the material used is affixed thus:- $(\frac{\mu}{\rho})_{Al}$. This signifies that the absorption-coefficient of the radiation was measured by placing Aluminium in the beam.

Mention has already been made of the method of showing that the intensity of a beam of X-radiation decreases when it passes through matter. In these researches, tests are made on the transmitted radiation and on the radiation scattered along a direction making an angle θ with the incident/

incident radiation. Each beam is received into a separate electroscope, of the gold-leaf type. Each beam produces ionisation in the chamber of the electroscope and so the charge on the gold-leaf is diminished and the deflection of the gold-leaf from the fixed electrode reduced. If there is no material placed in the path of the transmitted and scattered beams between the scatterer and the electroscopes, the ratio of the change in deflection of the leaf in the electroscope receiving the scattered radiation to the change in deflection of the leaf in the electroscope receiving the transmitted radiation is denoted by $^{s}/_{p}$. If equal thicknesses of the same material are placed in each beam between the scatterer and the electroscope, the ratio then obtained is denoted by $^{s'}/_{p'}$. If material be placed in the transmitted beam and not in the scattered, the ratio is now written $^{s}/_{p'}$; if in the scattered and not in the transmitted, it is written $^{s'}/_{p}$. The precautions and methods of measuring these quantities will be discussed later.

Henceforth, in this paper, the transmitted and incident beams will be termed the primary while the scattered will be called the secondary beam. The absorbing sheets of material placed in a beam to reduce its intensity are called filters, the name of the material being given.

HISTORICAL SURVEY OF PREVIOUS RESEARCH ON THE J-PHENOMENON IN X-RAYS.

As early as 1903, BARKLA observed that, in addition to the K, L, M, etc. characteristic radiations, another radiation was emitted by substances of low atomic weight unless the incident radiation was kept "soft". After the existence of the K, L, M, etc. characteristic radiations had been definitely established, he found that the ratio of the energy of the electrons emitted by a substance when its K-characteristic radiation was produced to the absorption of energy from the primary beam caused by this K-radiation, increased regularly as the wave-length of the primary beam was decreased until a certain wave-length was reached, when a sudden increase in the ratio occurred. It was thought that this was caused by a new characteristic radiation of the J-series, of higher frequency than the K-series, because, when it was observed, there were also evident a corpuscular radiation, increased ionisation and increased absorption of the primary radiation. These phenomena had never before been observed except in conjunction with the production of a characteristic radiation.

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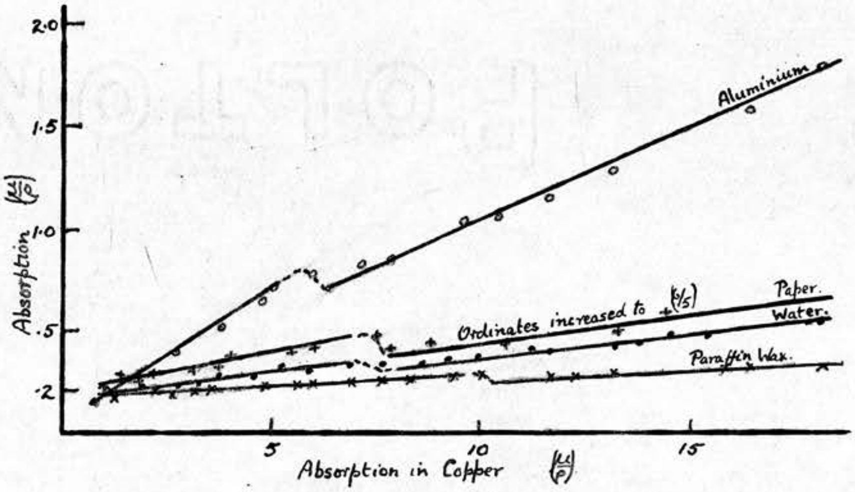
In later experiments, BARKLA and WHITE* measured the absorbability of a radiation in different substances, viz. aluminium, paper, water, paraffin wax and copper. The beams, of which they measured the absorption coefficient, were primary beams direct from an X-Ray tube except that they had been passed through absorbers in order to filter out the softer constituents. When the absorbability of the radiations was measured in the different substances and the values plotted against one another as shown in the accompanying curve (taken from the paper), the curves for any two substances showed similar characteristics.



The broken nature of the curve was taken to indicate the presence of an X-radiation characteristic of the substance whose absorption coefficients showed/

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* Phil. Mag., Oct.1917

showed the discontinuity. Similar curves had been obtained by BARKLA and SADLER* for K-radiations and by BARKLA and COLLIER+ for L-radiations.

In a paper to the Philosophical Magazine of May 1925, BARKLA gave a resumé of the work done on the subject and the results which had been obtained. By this time the J-discontinuities had been observed in association with phenomena very different from those usually accompanying the production of characteristic radiation. The conclusions reached from experiments of the type made by BARKLA and WHITE were:-

I. that the phenomenon was conditional on factors which had not previously been considered as governing X-ray phenomena.

II. that the changes in absorption were more sudden - being almost abrupt - than could be expected. It appeared that every constituent of the beam became suddenly more absorbed. This could not be true under Stokes' Law unless the beam were homogeneous.

III. that the appearance of the discontinuity appeared to be more associated with an absorption coefficient than with a wave-length.

IV. that, after the rise in absorption had taken place in one substance, the transmitted beam was more absorbable in other substances, although these substances showed their own absorption discontinuity.

V/

* Phil. Mag. May 1909. + Phil. Mag. June 1912.

V. that the change of critical absorption coefficient for the discontinuity with the atomic number of the absorbing substance was small and the critical absorption coefficient decreased with increase of atomic number.

VI. that the series of critical absorption coefficients in the elements cut across the K-series of absorption coefficients.

Experiments by BARKLA and MACKENZIE,* extended this idea that the rise in absorption was more associated with an absorption coefficient than with a definite wavelength. They observed that the activity of a compound radiation, produced by the superposition of two scattered radiations, was not the sum of the activities of the two constituent radiations. Each beam, as far as the appearance of the J-phenomenon was concerned, acted as a whole, while the compound beam, consisting of the two, showed, not the two discontinuities but one appropriate to itself as a whole. Thus a sort of "temperature" analogy was introduced. The authors also observed that beams of X-rays scattered in directions making angles of 60° and 120° with the primary beam differ, if at all, in one of the following two ways:-

(1) by the beam at 120° showing the J-discontinuities.
(2) by a continuous difference in absorbability in some substances.

BARKLA/

* Phil. Mag. Feb. 1926.

BARKLA and KHASTGIR[+] showed that, if a heterogeneous radiation was scattered, the scattered beam had either the same absorbability as the primary or else showed a well-marked difference of absorbability when measured in any substance. They also observed that while the scattered radiation might have a different absorbability from the primary in some substances, its absorbability was exactly that of the primary in other substances; and also that a scattered radiation, after being transmitted through a substance which showed the difference between the primary and secondary radiations, showed its absorbability to be exactly that of the primary when measured in other substances. They also observed that no matter what the angle of scattering, the difference, if any, between the primary and the scattered beams was of the same amount and that if any further difference occurs, it does so abruptly by a jump. They state their conclusion thus:-

"We find absolutely no indication of the COMPTON wavelength change on scattering and all the laws governing the change observed by us - the manner of its appearance, its magnitude, its variation with frequency and with angle of scattering, appear entirely at variance with COMPTON'S view".

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+ Phil. Mag. Sept. 1926.

This apparent conflict, they suggested, might be due to the fact that a certain number of the properties of an X-radiation were associated with something analagous to 'temperature' of the radiation rather than the frequency. The authors thus observed, instead of the COMPTON wavelength change on scattering, the J-phenomenon. Though it was governed by laws different from those governing the COMPTON-effect, the J- phenomenon showed a remarkable correspondence with the COMPTON effect. They were therefore left with the two alternatives:-

I. that no COMPTON effect had been observed by them.

II. that X-ray activity had to be divorced from the wavelength of the radiation and a new system of laws introduced.

They also suggested that the difference between the primary and the scattered beams could be accounted for by supposing that the structure of the scattered radiation was different from that of the primary, the structure of the scattered radiation being more favourable to the appearance of the J-phenomenon. A greater coherence in the secondary beam would have been sufficient to ensure this and this greater coherence could be obtained in a number of/

of ways. This led to a discussion of the possible effect on the scattered beam of changes in the method of excitation of the tube, a type of experimental procedure treated in a paper by BARKLA and MACKENZIE*.

The results of scattering experiments by the authors were shown to depend on the frequency of the interrupter fitted to the induction coil supplying the High Tension to the tube. Thus they were able to conclude that the activity of an X-radiation appeared to be due to the stream of the X-radiation as a whole and not to the constituent frequencies of the radiation.

BARKLA and WATSON,** in a series of experiments in which the current through the tube was carefully controlled and kept constant during an experiment, observed that the critical absorption coefficient, at which a given discontinuity occurred, varied slightly as the current through the tube was varied. This suggested that the non-appearance of the J-phenomenon, in some experiments, was due to the variable nature of the current through the tube. By keeping the current steady they were able to control the appearance of the J-phenomenon. They also found, in their experiments, that there was no/

* Phil. Mag. Nov. 1926. ** Phil. Mag. Nov. 1926

no difference between the absorbability of the primary and secondary radiations except by the occurrence of the J- discontinuities in the progressive absorption of the scattered radiation.

Other experiments by BARKLA and KHASTGIR[*], on Modified and Unmodified Scattered X-Rays, showed that a scattered radiation which is modified, or shows the COMPTON effect, as measured by its absorbability in a number of substances may be either modified or unmodified in another substance.

BARKLA[**], in June 1928, published the results of a number of experiments in which the change from unmodified to modified scattered radiation was exhibited not by the beams passing through a certain critical average frequency as measured by an average absorption coefficient but by the superposition of radiations of the same frequencies in almost the same proportions. Unmodified radiations were obtained from air and thin scatterers but the modification rapidly increased in amount with the increasing thickness of the scatterer, finally reaching a limiting value. The results again pointed to the view that the modification depended on some kind of coherence in the radiation.

WATSON/

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* Phil. Mag. Oct. 1927. ** Phil. Mag. June 1928

WATSON* comparing the ionisations produced by two secondary beams from a scatterer whose K characteristic radiation was produced, found that, with equal amounts of absorbing material in the path of each beam, the ratio of the ionisations did not alter continuously with increase in the amount of absorber, if the tube current was carefully controlled. Discontinuities were, however, apparent in the value of the ratio, these discontinuities appearing to be identical with the J-discontinuities already observed.

BARKLA and SEN GUPTA,** measuring the absorbability of a given radiation near a J-discontinuity, found that it depended on the other radiations transmitted through the absorbing substances at the same time. Thus it always appeared in their experiments that the processes of absorption depend on a coherence of the various constituents of the radiation traversing the matter.

Many other papers have been published giving evidence of the existence of the J-phenomenon, while a number record only unsuccessful attempts to observe it. In the account of the results of recent experiments, the J-phenomenon was evident at the beginning/

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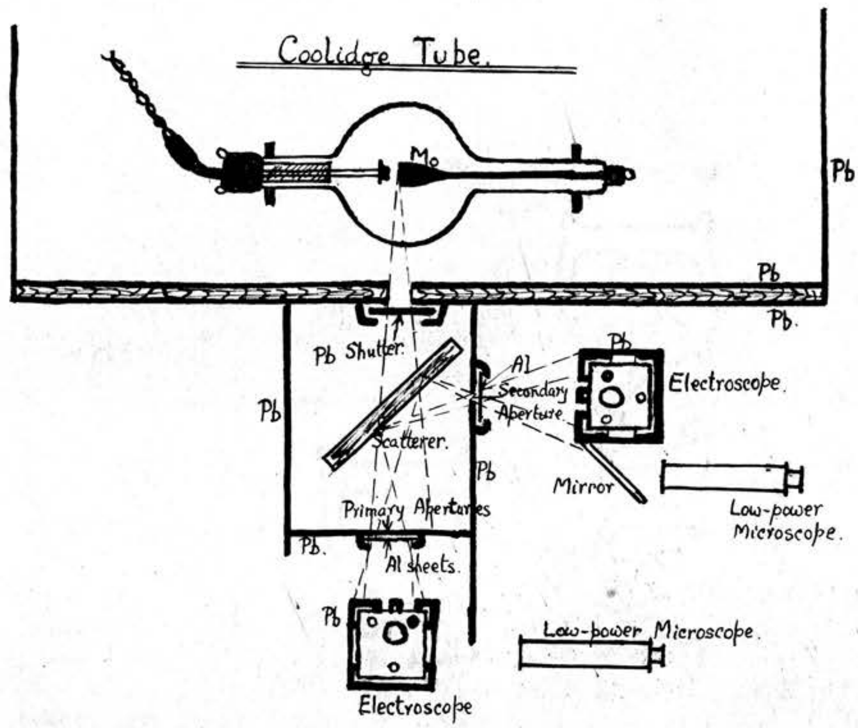
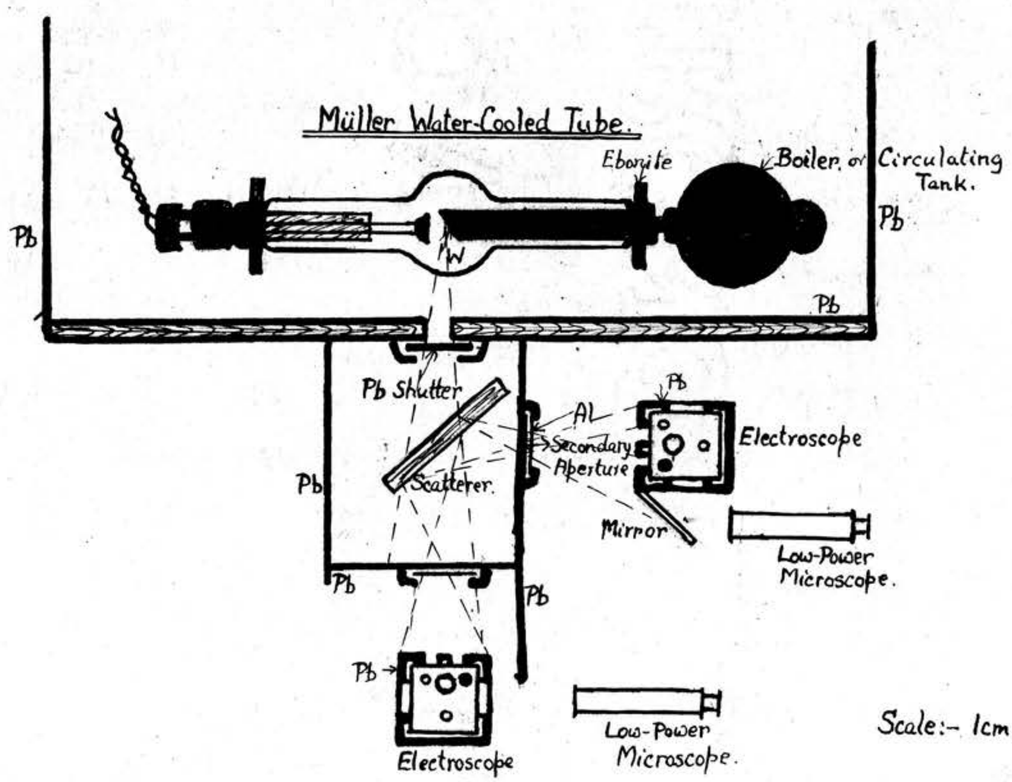
* Phil.Mag. June 1928.

** Phil.Mag. April, 1929.

beginning of an experiment, or developed during the progress of the experiment. It is hoped that the results observed and noted herein, may help to throw some light on the cause of this phenomenon of X-ray scattering.

ARRANGEMENT/





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Arrangement of Apparatus.

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ARRANGEMENT OF APPARATUS.

As will be observed from the diagrams opposite, the X-Ray tubes were enclosed in a lead-covered box, which had a double thickness of lead on that side nearest the apparatus used to compare the radiations on which tests were made. An aperture in this side of the box allowed a beam of X-radiation to fall on any slab of substance placed in front of it. The focus spot of the tube was placed in a horizontal line with the centre of the aperture and in such a way that this line was perpendicular to the face of the box. The scattering substance was surrounded by lead sheets or screens. Apertures were made in these screens to allow the beams experimented on to pass out and be compared by means of the ionisations produced by them in cubical gold-leaf electroscopes set to receive them. The beams tested in this research were the undeflected primary beam and one consisting of radiation scattered through approximately 90°. The centres of the apertures necessary to separate out these two beams were made to lie in the same horizontal plane as the line containing the focus spot and the centre of the aperture in the box.

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The slab used to scatter the radiation from the tube, was placed so that subsequent to the excitation of a secondary radiation it absorbed the primary and secondary beams in exactly the same degree, i.e. the thickness of material traversed by the primary beam was the same as the thickness traversed by the scattered beam. Thus the scatterer, in the form of a slab, was inclined at an angle of 45° to each beam, and so that the transmitted and scattered beams emerged from the face opposite to the face on which the beam from the tube was incident.

Each beam thus separated was passed into an electroscope of the cubical gold-leaf type, the leaf in such electroscope being charged to a potential of 240-300 volts. The electroscopes were contained in lead boxes. An aperture in one face of the lead box, placed normal to the incident beam of radiation, allowed radiation to pass through an aluminium 'window', into the electroscope chamber. Each electroscope had a 'window' of .01 cms. thickness of aluminium and, in order to prevent radiation being absorbed by the gold leaf and electrode, and so producing corpuscular radiation, which would affect the ionisation in the chamber, a strip of lead was placed down the middle of the 'window'. Characteristic corpuscular/

corpuscular radiation from the walls of the chamber was prevented by lining the interior walls of the electroscope with a layer of four sheets of filter-paper. The aperture in the boxes containing the electroscope was of such a size that no radiation could strike the side walls of the electroscope. Thus the ionisation produced inside the chamber of the electroscope, was produced by X-radiation in the air of the electroscope and not by corpuscular radiation from the metal walls of the electroscope.

Since the intensity of the primary beam was much greater than that of the scattered beam, each beam was passed through apertures, the respective areas of these apertures being so arranged that during a given exposure of the scatterer to radiation, the change of deflection of the primary gold-leaf, was very nearly equal to the change of deflection of the secondary gold-leaf. The change in deflection of the leaves was measured, by focussing the image of the gold-leaf on the scale of a low-power microscope.

In the case of the secondary leaf, direct focussing was impossible, so that the microscope had to be focussed on the image of the leaf in a plane mirror.

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In using this ionisation method of comparing beams of radiation, care had to be taken that the ionisation current causing the change in the deflection of the gold-leaves, was saturation current, the primary and secondary apertures being reduced in area till this was the case.

In order to avoid errors due to variations in the sensitivity of the electroscope, the deflection of the gold-leaf of the primary electroscope was allowed to move over ten divisions of the scale, beginning, for each exposure, at the same initial reading on the scale. During this change of deflection, the secondary leaf moved from its initial position, which was kept as nearly constant as possible, over a certain number of divisions.

The ratio of the number of divisions moved through by the secondary leaf to the number of divisions moved through by the primary leaf, was taken as the measure of $^s/p$, defined above.

During the experiments the primary aperture consisted of a number of small holes, .5mm. in diameter, while the secondary aperture was a/

a single hole varying in diameter from 2 cms. to 4 cms. The size of the apertures used depended on the nature and thickness of the scattering substance.

THE SOURCES OF RADIATION

During the early part of the research, the X-radiation was obtained from a Coolidge Tube with Molybdenum anticathode, and during the latter part of the research, it was obtained from a Müller Water-Cooled Tube with Tungsten target.

In the case of the Coolidge Tube, the X-radiation from the tube left the anticathode at "glancing-angle", the tube being placed so that its axis was parallel to the front of the box. The face of the anticathode was cut almost exactly perpendicular to the axis of the tube. Due to the nature of the tube, the focus spot could vary appreciably in position due to the expansion and contraction of the anticathode under the uncontrolled heating effect of the electron stream.

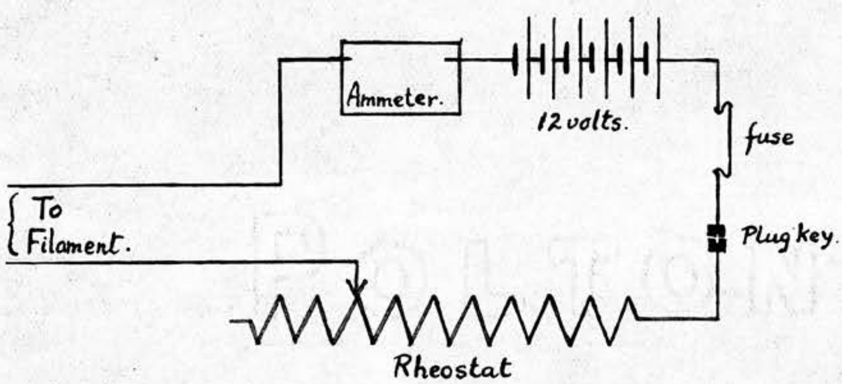
With the Müller tube however, the rays used were those emerging at an angle of 45° from the face of the anticathode which was cut at 45° to the axis of the tube, which was placed, as in the case of

the/

the Coolidge Tube, with the axis parallel to the front of the box. In this tube, large variations of temperature on the anticathode were avoided by water circulation in a cistern attached to the anticathode. Water circulating in the cistern was boiled by the heating effect of the electron stream, and the temperature thus kept fairly constant. Thus the focus-spot on the anticathode remained almost stationary during the experiments. There was at least no shift along the axis of the tube. Vibrations tended to be set up, due to the water 'bumping' on boiling, but this was minimised by securely clamping the ebonite stand on which the tube was supported.

SUPPLY OF FILAMENT CURRENT AND TUBE POTENTIAL

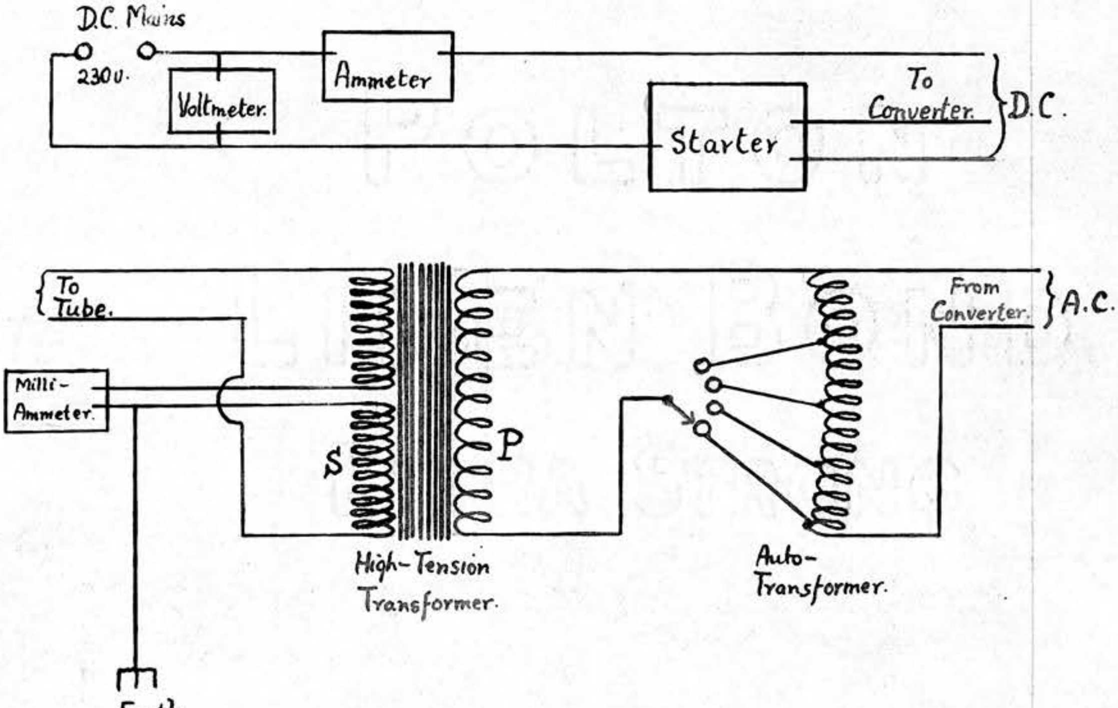
The filament of each tube was heated by current from a battery of accumulators. The current could be varied by means of a rheostat connected in series with the filament and cells as shown under:-



Filament Heating Circuit.

The high tension supply to the tube was obtained as shown in the diagram under. A rotary converter, driven by the city mains at 230 volts D.C. supplied A.C. at 130 volts to an auto-transformer fitted with tappings so that, in conjunction with the primary of a high-tension transformer, peak voltages of 15,30, 45 and 60 kilovolts respectively could/

could be applied to the tube from the secondary of the transformer. The secondary windings of the transformer was earthed at its mid point, and, in the gap at this point a milliammeter was inserted to give the current passing through the tube at any instant.



High Tension Supply to Tube.

VARIATION of the RATIOS $^{s}/_{p}$ and $^{s'}/_{p'}$ WITH AVERAGE *HARDNESS of a HETEROGENEOUS BEAM of X-RADIATION.

If, when X-Radiation is scattered by a substance, the COMPTON increase in wavelength occurs, the values of the ratios $^{s}/_{p}$ and $^{s'}/_{p'}$ should vary as the radiation incident on the substance is hardened. The value of the ratio $^{s}/_{p}$ for a given hardness of the radiation will be different from the corresponding value of the ratio $^{s'}/_{p'}$ observed for the same hardness. The variation of the value of the ratio $^{s'}/_{p'}$ with increasing hardness of the incident radiation does not obey such a simple law when the material absorbing the transmitted and scattered radiations emits a characteristic radiation within the range of hardness used in the experiment. Since the primary beam should contain a constituent radiation of frequency higher than the frequency of any component of the scattered beam, the primary beam will, at some given hardness contain, as a constituent radiation, a radiation, the wavelength of which is shorter than the wavelength of one of the characteristic radiations of the absorbing substance. Thus by Stokes' Law, the characteristic radiation of the absorbing subatance may be, and is, produced in the primary beam, while the/

* Note:- The author has used the terms "hardness", "hard" etc, with the meaning, "absorbability as given by $(\mu/\rho)_{Al}$", "absorbable" etc. Possibly these latter terms should have been used in preference to those actually used.

the secondary beam does not contain a constituent of wavelength shorter than that of the characteristic radiation produced. Thus the primary beam will be absorbed to a greater extent than normal and, therefore, the ratio $^{s'}/p'$ will increase quickly. Soon, however, on further hardening of the beam of radiation from the tube, the secondary will contain a constituent radiation of wavelength shorter than that of the characteristic radiation which has been produced in the primary and thus the absorption of the secondary will increase at this hardness and the ratio $^{s'}/p'$ begin to decrease.

If, on the other hand, there is no increase of wavelength on scattering, and each component radiation is scattered in the same proportion, the ratios $^{s}/p$ and $^{s'}/p'$ should remain constant and equal to one another throughout the range of hardness on which experiments may be made. This will be obviously the case since the secondary and primary radiations must be of equal hardness.

The results of actual experiment do not bear this out entirely. These results can be classified as follows:-

(a) Results which are consistent with the COMPTON wavelength change on scattering.

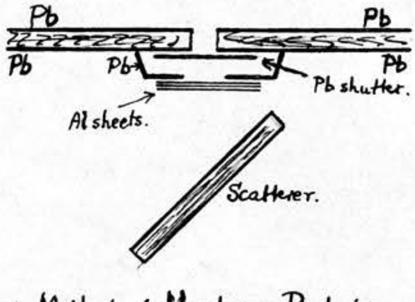
(b)/

(b) Results which, while agreeing in some respects with the Classical ideas, show definite inconsistencies, which may be characterised thus:-

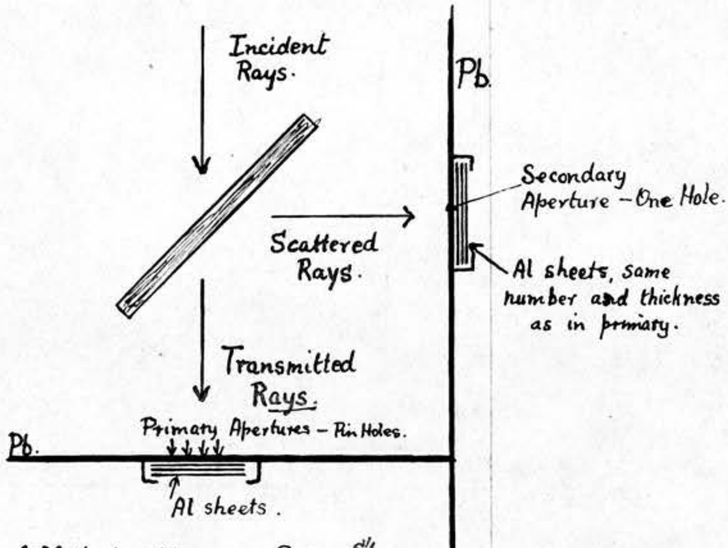
The ratios s/p and s'/p' may not be equal for a given hardness of radiation, but the ratios s/p and s'/p' are constant in value over ranges of hardness of the radiation, these ranges not necessarily being the same for both ratios. The change in value of the ratios, when it does occur, takes place at definite well-marked hardnesses of the incident radiation, as represented by an average mass-absorption coefficient measured in aluminium.

These latter results cannot be explained either on the COMPTON theory or on the Classical theory and no satisfactory explanation has so far been put forward.

These results have been observed by previous experimenters. The work of the writer showed the same results. In the experiments of the author, the maximum voltage which could be applied to the tube was a peak voltage of 60 K.V. In order to harden the beam of radiation further the only method available was to pass the radiation from the tube through filtering sheets of aluminium and thus to absorb the softer constituents of the radiation. By this means, X-radiation varying in hardness from $(\mu/\rho)_{Al} = 5.0$ to $(\mu/\rho)_{Al} = 0.9$ could be made incident on the scatterer.



a) Method of Hardening Radiation



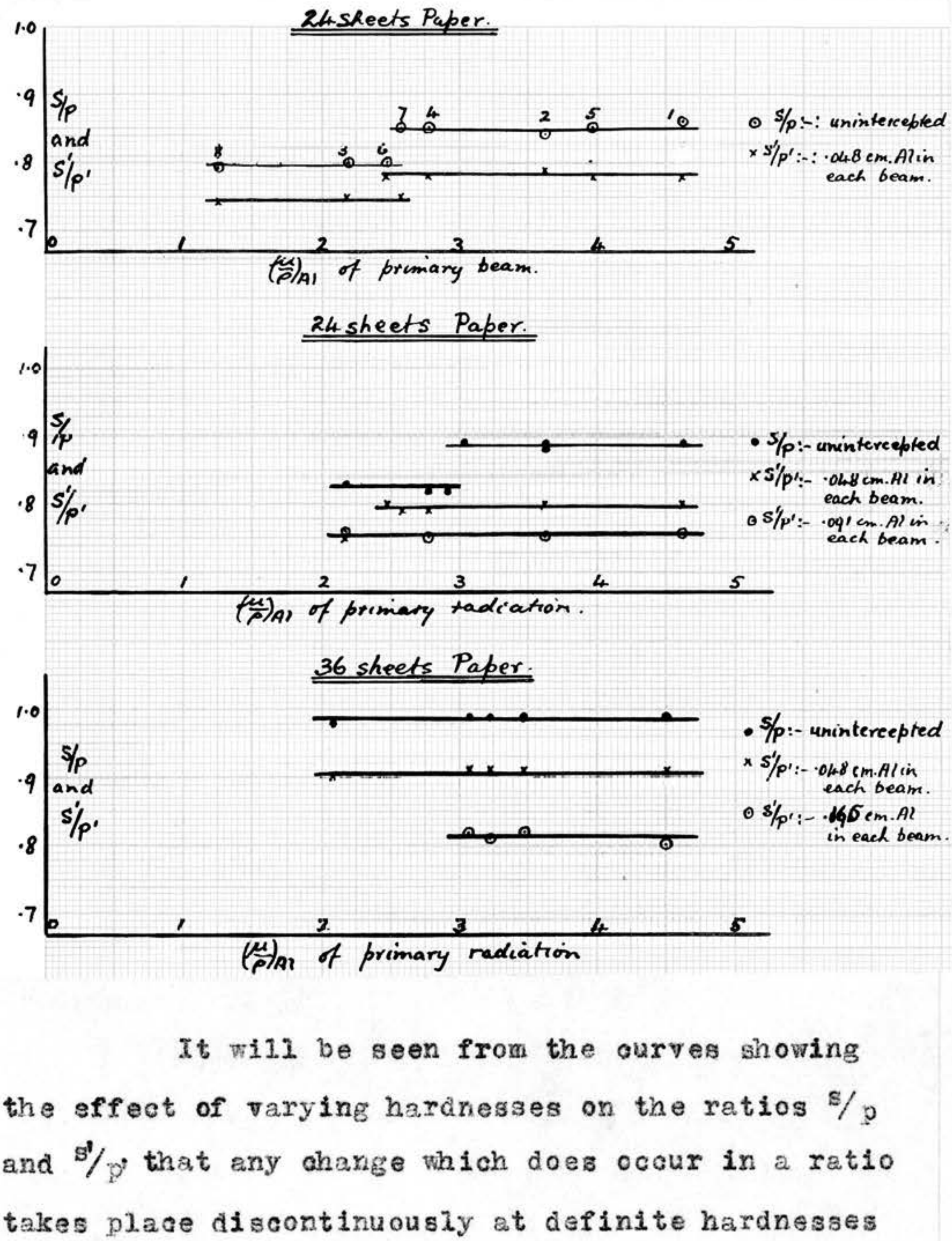
b) Method of Measuring Ratio s'/p'

The scatterers in these experiments consisted of a number of sheets of paper or of a thick slab of paraffin wax or such substance. The ratio of the change of deflection of the leaf in the secondary electroscope to the corresponding change in deflection of the leaf of the primary electroscope was observed for different beams of radiation

(a) when the beams were unintercepted.

and (b) when each beam had to pass through a given thickness of aluminium.

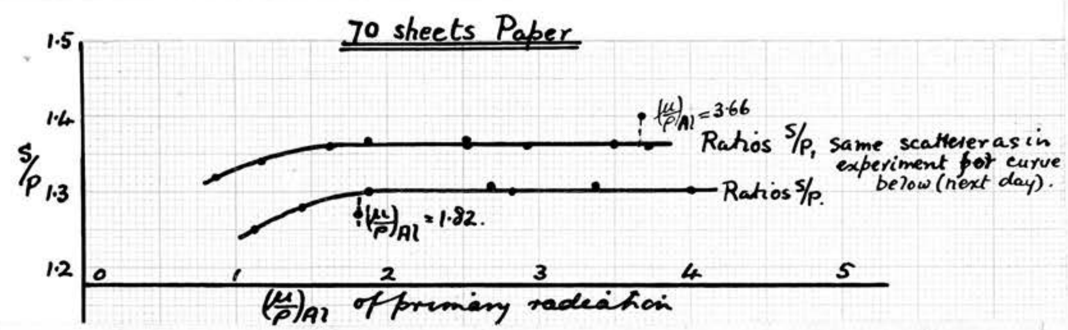
The curves reproduced below show the effect on the ratios (a) and (b) of changing the hardness of the beam. [The ratios (a) and (b) are merely the quantities s/p and s'/p' (for a given thickness of filter)]. It should be mentioned that the hardness of the incident radiation was not increased continuously but was generally altered at random by varying the absorbing sheets of Aluminium in a haphazard fashion.



It will be seen from the curves showing the effect of varying hardnesses on the ratios $^s/_p$ and $^{s'}/_{p'}$ that any change which does occur in a ratio takes place discontinuously at definite hardnesses of the incident radiation; in the curves shown, these hardnesses are given by $(\frac{\mu}{\rho})_{Al}$ = 2.5 and 3.0. In some observations, the ratio $^s/_p$ alone changed, the ratio/

ratio s'/p' remaining constant over the range of hardnesses on which experiment was made. In other observations, a change was noted in both ratios, usually at the same hardness for both ratios.

In some experiments, where no sudden change in the ratio s/p was observed, this ratio began to decrease in value in the region of the hard X-rays, the decrease commencing at a hardness corresponding to $(\frac{\mu}{\rho})_{Al}$ = 1.50. Similar results have been obtained by BARKLA* and KHASTGIR.



It may also be noted that the unintercepted ratio s/p shows more tendency to discontinuity than any intercepted ratio s'/p' and that the greater the thickness of Aluminium in each beam, the greater the likelihood od the ratio s'/p', corresponding to it, remaining constant. This, of course, can be ascribed to the intercepted beams being rather harder than the unintercepted beams and therefore being more nearly homogeneous, as far as that is possible by/

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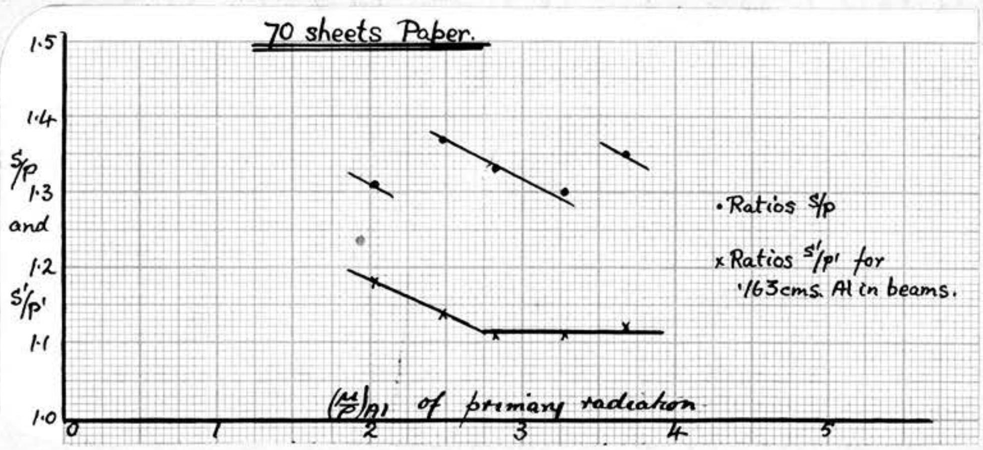
* Phil. Mag.

by filtering a heterogeneous beam.

In the curves shown for scattering from 70 sheets of paper, the curve obtained on the second day differed from that of the previous day, only in the magnitude of the ratios $^{s}/_{p}$. Both curves show the slow fall in the value of $^{s}/_{p}$ in the region of the hard radiation, the decrease commencing at a hardness given by $(\mu/\rho)_{Al} = 1.5$ approx.

The result observed in one experiment on the variation of the ratios $^{s}/_{p}$ and $^{s'}/_{p'}$ with hardness of the incident radiation, made after a "filtering" experiment of long duration, gave an interesting, although as yet unconfirmed, result.



It will be observed that the curve is irregular and discontinuous. These sudden changes seem to occur at $(\mu/\rho)_{Al} = 3.4$ and $(\mu/\rho)_{Al} = 2.4$ hardnesses at which J-discontinuities have been observed to occur.

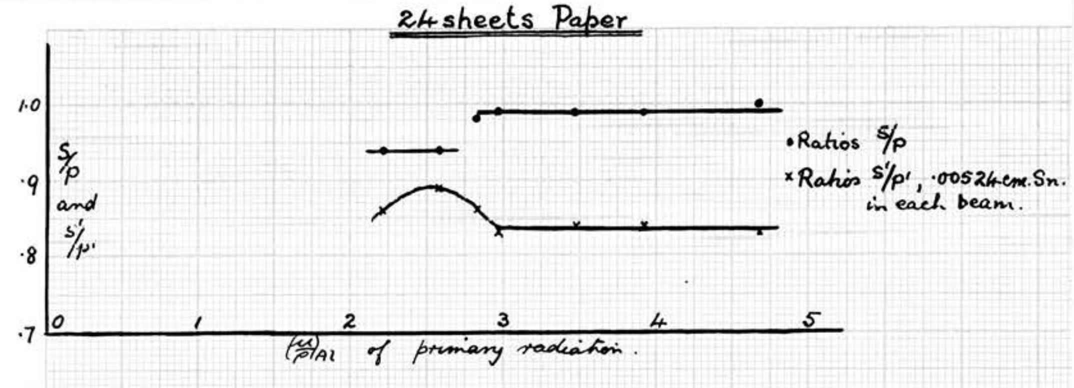
These/

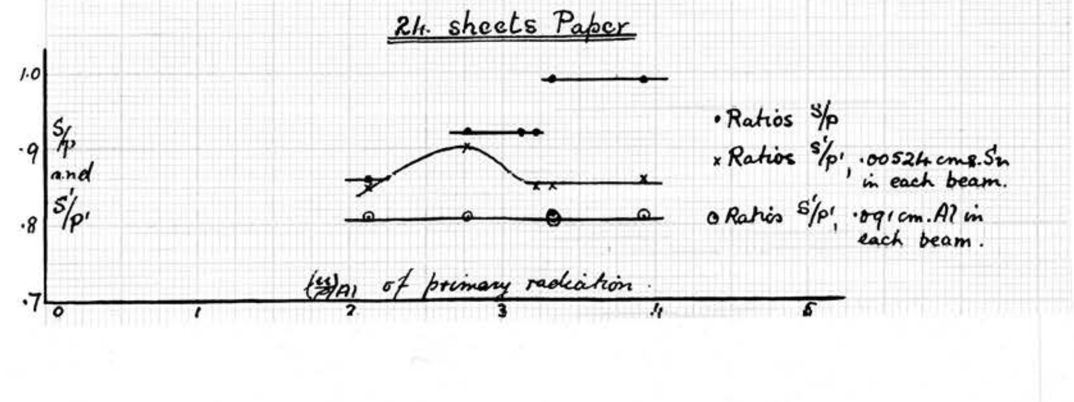
These changes occur in the ratio $^{s}/p$, the ratio $^{s'}/p'$ having a constant value at the softer end of the range of hardness experimented on and then commencing to increase in the same way as the ratio $^{s}/p$ at a hardness $(\mu/\rho)_{Al.}$ = 2.7 approximately.

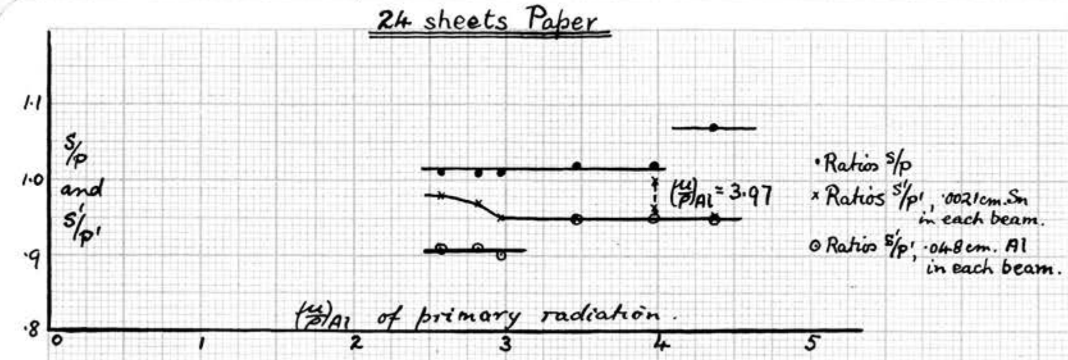
Although nothing definite can be said about a result from a single experiment, it is interesting to note its significance in the light of results obtained from filtering experiments after prolonged exposure of the scatterer. It may be that this type of result is occasioned by what is called the 'exposure-effect' of radiation on the scattering material. What is meant by this term will be more apparent after the results of filtering experiments have been discussed.

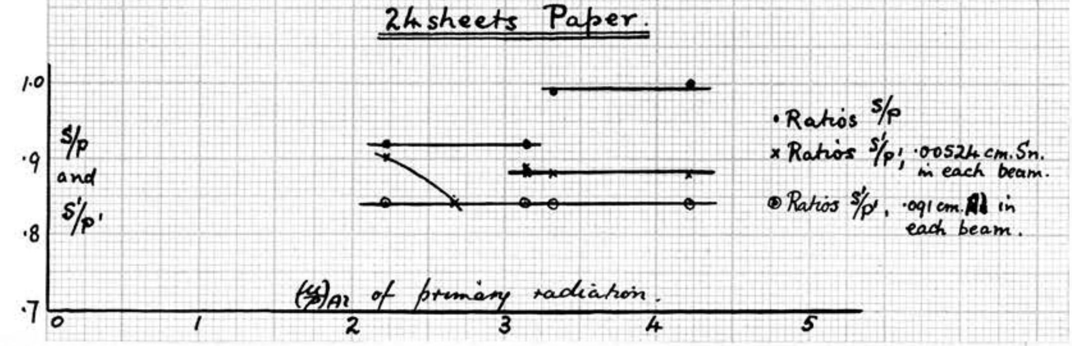
A number of experiments on the variation of the ratios $^{s}/p$ and $^{s'}/p'$ with absorbability of the radiation were made, using scatterers of filter paper with absorbing sheets of tin placed in the primary and secondary beams. The ratio $^{s'}/p'$ when tin absorbing sheets were used did not remain constant but, in a well defined region of hardness of the incident radiation began to increase and later to decrease. This was due to the fact that the secondary radiation was softer/

softer than the primary, although this was not observable from the values of the ratio s/p or s'/p' for aluminium absorbers. Thus, for the tin absorbing sheets the primary having a component of frequency higher than the frequency of any component of the secondary, will cause the characteristic radiation from tin to be excited to a great extent in the primary beam, while the secondary is able to excite it to a very small extent. Thus the primary beam will be absorbed to a greater extent than the secondary in this initial stage and the ratio s'/p' when tin absorbing sheets are used will thus increase. Soon, however, as the incident beam is filtered more and more, the secondary becomes almost of the same quality as the primary and so the absorption of the secondary beam increases and the ratio s'/p' will begin to decrease.









These experiments showed that the ratio $^{s'}/_{p'}$ measured for tin absorbers in the beams was generally unbroken and continuous whether the ratio $^{s}/_{p}$ was continuous or not. In a few cases, the ratio $^{s'}/_{p'}$ for absorption by tin was also discontinuous, the discontinuity occuring at the same hardness for both ratios $^{s}/_{p}$ and $^{s'}/_{p'}$ for tin while the ratio $^{s'}/_{p'}$ observed for absorption by aluminium remained constant throughout. The observed discontinuities occurred at hardnesses previously noted with the additional hardness given by $(\frac{\mu}{\rho})_{Al} = 2.7$.

SUMMARY OF RESULTS.

The following conclusions may be drawn:-

I. Discontinuities are observed more frequently in the unintercepted ratio than in any intercepted ratio.

II. The greater the thickness of filtering aluminium through which the beams pass, the less frequently are discontinuities observed in the ratio s'/p'.

III. The thicker the scatterer, the less the probability of any discontinuity occurring.

IV. Discontinuities, when they do occur, do so to an approximate degree, at definite hardnesses of the primary radiation, viz: $(\mu/\rho)_{Al}$ = 4.0, 3.4, 3.0, 2.7 and 2.4.

V. The secondary beam is apparently more absorbable than the primary.

To these a possible sixth may be added:-

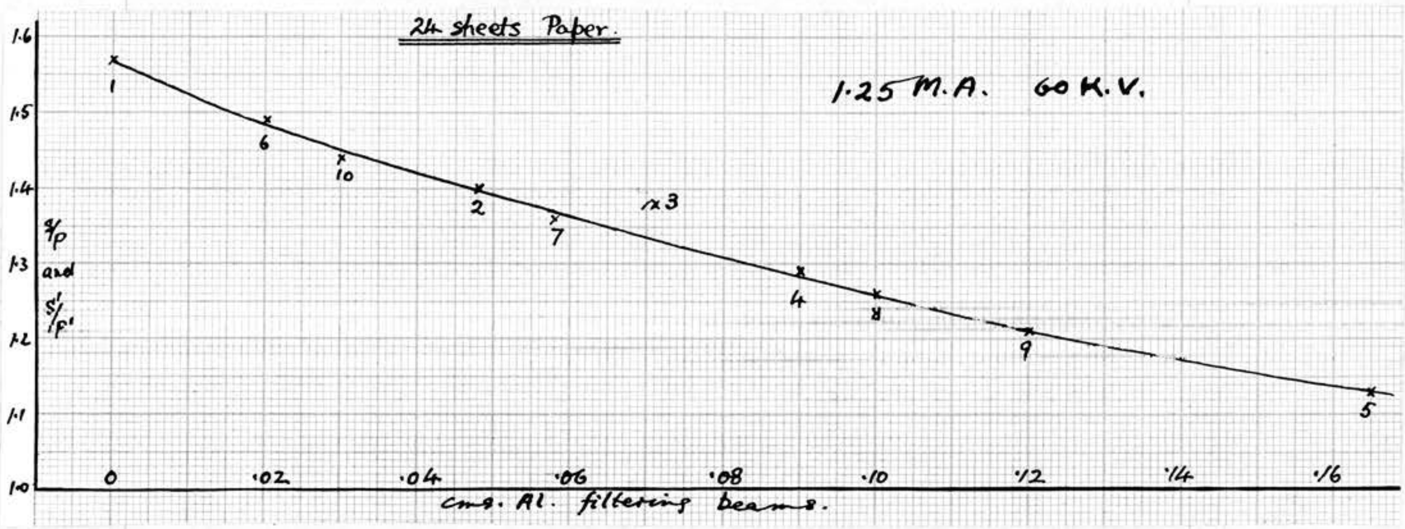
The results may be affected by the length of time for which the scatterer has been exposed to X-radiation.

FILTERING EXPERIMENTS.

As previously mentioned, filtering experiments are concerned with the behaviour of the ratio $^{s'}/_{p'}$ when the thickness of the equal amounts of absorber in the primary and secondary beams is varied. The thickness of these absorbers or filters, which were placed at the same distance, in each beam, from their respective electroscopes, was, in some experiments continually increased or decreased, while, in other experiments, the thickness was varied in a haphazard fashion. In the curves drawn to show the behaviour of the observed ratios $^{s'}/_{p'}$ with the thickness of the filters, the number attached to points on the curve, indicates the order in which the observations were made. If the thickness was increased steadily, an arrow points to increasing thickness, whereas if the thickness was decreased steadily, an arrow points to zero thickness.

As explained previously, if the COMPTON change of wavelength on scattering has taken place, the primary and scattered radiation will not be equally absorbable, the scattered radiation will be softer than the primary and thus the ratio $^{s'}/_{p'}$ should vary steadily as the thickness of filter in each beam is increased. As the beams are filtered more and more the/

the ratio will change less and less quickly, since both beams will tend, in the limit, to become equally hard. Thus the curves of $^{s'}/_{p'}$ against thickness of filters should show a regular slope and should have a slight concavity.



Results of this nature were obtained by the writer. The general characteristics of the curves were as required by what is outlined above. The decrease in the ratio $^{s'}/_{p'}$ was regular as the thickness of the filtering material, (aluminium), was increased.

The results of other experiments did not show this regular gradual fall in ratio. This other type of result has already frequently been observed by earlier experimenters* in this Laboratory. The results referred to were those showing the appearance of the J-discontinuities.

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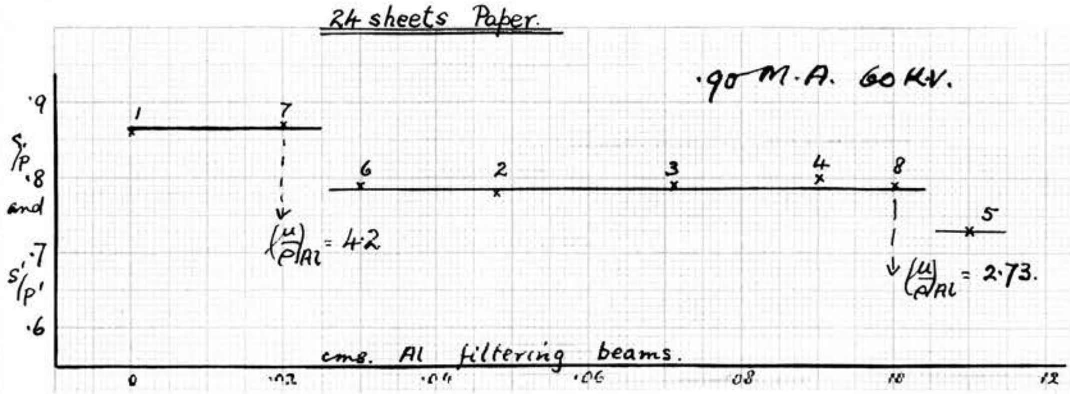
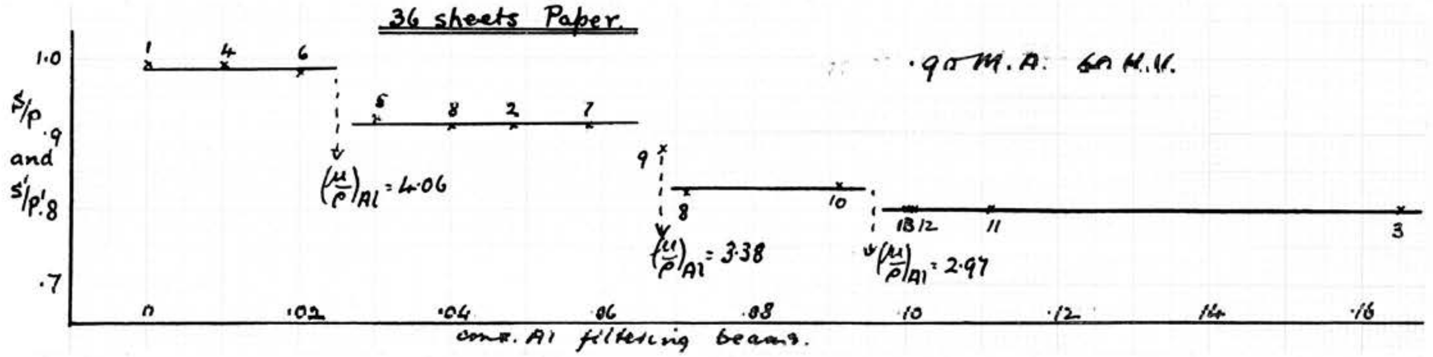
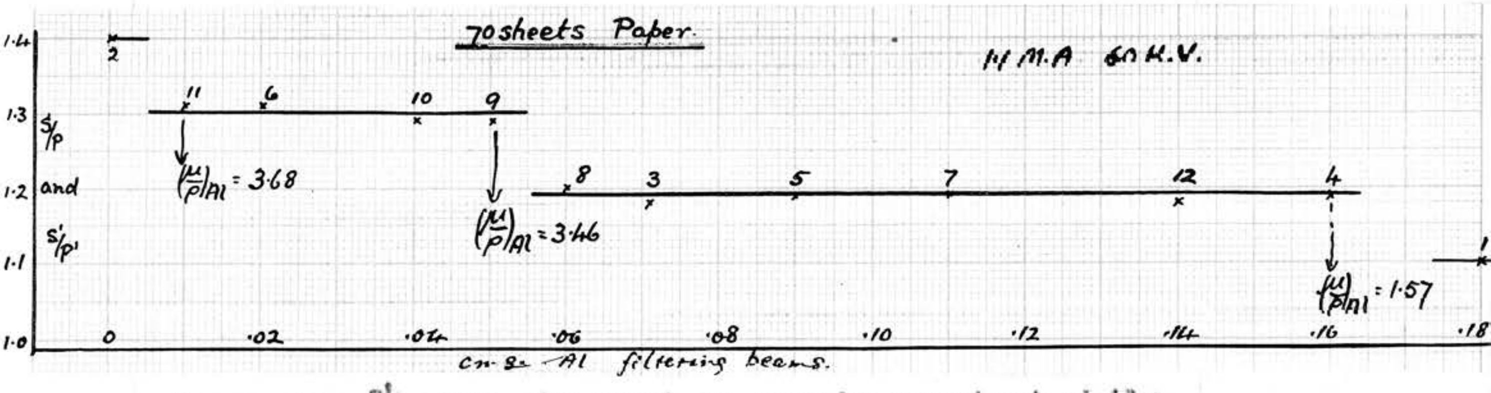
* BARKLA and MACKENZIE, Phil. Mag. Feb. 1926.







The ratio s'/p' was observed to remain constant while the thickness of filtering aluminium was increased until at a *definite average hardness of the primary beam, the value of the ratio fell by some 8% and remained constant at this lower level until another definite/

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* By definite is meant that a discontinuity always seemed to occur near certain absorbabilities of the radiation as measured by $(\mu/\rho)_{Al}$.

definite average hardness was reached when a further fall in ratio took place. Thus for a certain range of average hardness of the radiation the primary and secondary beams were equally absorbable; when this limiting hardness was reached, the absorbability of one or the other changed and the beams again became equally absorbable but at the different "level". The discontinuities, when they occurred, were observed to occur abruptly at certain quite definite hardnesses of the beam, as measured by the average absorption coefficient of the radiation in aluminium. The hardnesses at which the discontinuities occurred in the writer's experiments were those given by

$$\left(\frac{\mu}{\rho}\right)_{Al} = 4.0,\ 3.7,\ 3.4,\ 3.0,\ 2.7.$$

These observed by earlier experimenters were given by

** $\left(\frac{\mu}{\rho}\right)_{Al} = 3.76,\ 3.24,\ 2.44,\ 1.94,\ 1.40.\ 0.73,\ 0.47$

There is no possibility of mistaking the type of result obtained, the change in ratio being altogether outside the possible experimental error. It will be observed from the curves that, when a discontinuity does occur, it takes place in the direction in which the slope required by the quantum theory of scattering would proceed. Thus the two/

** BARKLA and WATSON, Phil. Mag. Nov. 1926.
These values have been observed to vary with the current through the tube.

two types of result would appear to be inter-related in some way.

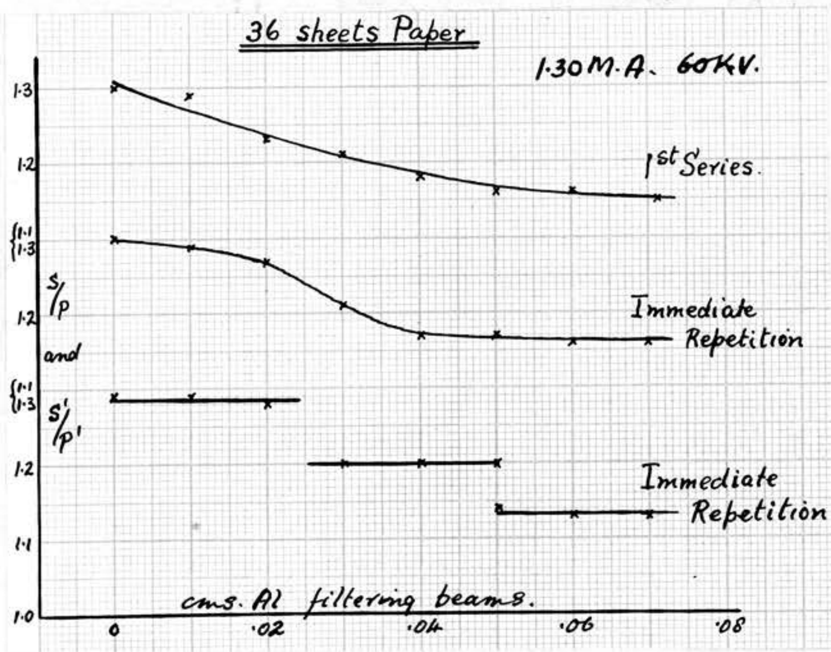
The mere obtaining of such results, although interesting in themselves, does not lead far unless some method can be found of passing from one type of result to the other, either by altering the conditions of the experiment or by changing some part of the scattering or measuring devices. A possible method of achieving this was manifested during a series of experiments in which filtering experiments and experiments on the variation of $^s/_p$ with the average hardness of the radiation were being carried out together. The scatterer in these experiments was composed of a number of sheets of filter-paper. It was observed that if a filtering experiment was made just prior to the experiment on the variation of $^s/_p$ with average $(\frac{\mu}{\rho})_{Al}$ of the radiation, the resulting curve, showing the variation of $^{s'}/_p$, with the thickness of Aluminium filters in the beams, was the slope required by the COMPTON change of wavelength theory; if, however, the filtering experiment was made immediately after the completion of the other type of experiment, the resulting curve was of the type associated with the appearance of the J-phenomenon of scattering.

The/

The natural step, therefore, was to try the effect of exposing the scatterer to X-Radiation. This could be done in two ways, either before it was used in an experiment or while it was being used. This latter method had the advantage that, if a change took place due to exposure to radiation, the progress of the change would be made visible in the nature of the curves of successive filtering experiments, since the change would, in all probability, be a gradual one. Thus if the exposure of the scatterer had any effect on the results obtained in filtering experiments, the curves showing how the ratio $^{s'}/_{p'}$ varied with the thickness of the Aluminium filtering the beams should have changed, on continued use of the scatterer, from the initial slope to the discontinuous curve showing the presence of the J-phenomenon.

The experimental procedure was therefore quite straightforward. A scatterer, consisting of 24 sheets of filter paper in these initial experiments, was set up and a series of filtering experiments carried out, one after the other, there being no interval between the last observation required to complete one experiment and the initial observation of the next experiment, other than that usually necessary/

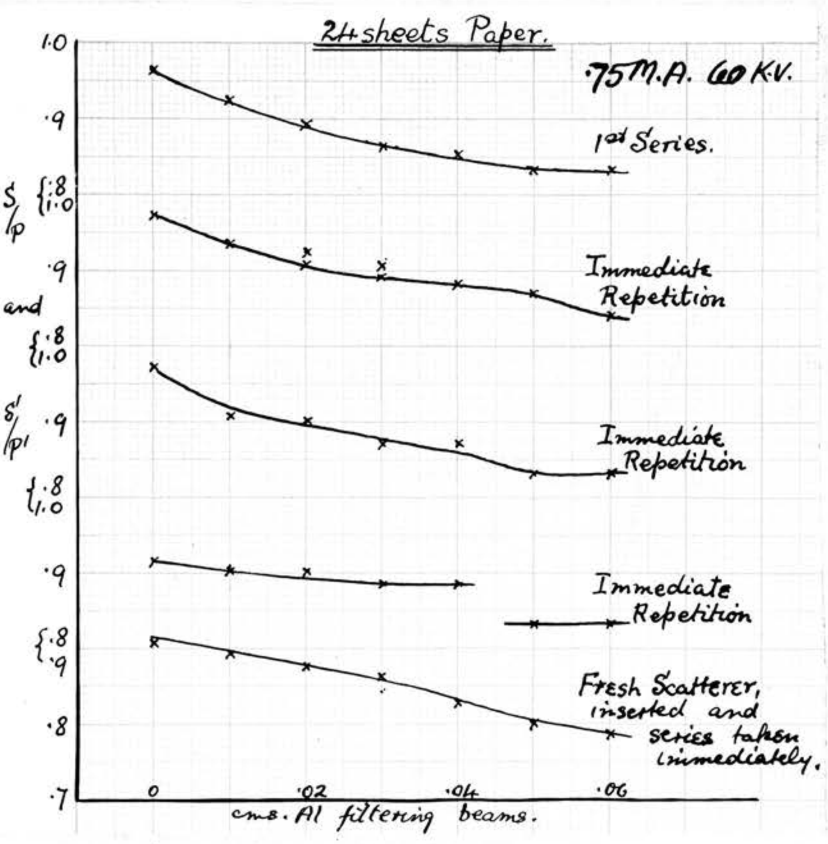
necessary in order to change the thickness of the filters and to charge up the gold-leaves. The gold leaves had, of course, to be allowed to settle properly after charging, before the exposure necessary for the observation was commenced. Thus a series of filtering curves were obtained, each curve being produced from a set of observations which contained one value of the ratio s'/p' for each thickness of filter used. The results were most instructive.



In the first curve, the slope was generally obtained but later curves showed a tendency to become more irregular and finally developed into the discontinuous/

discontinuous levels characteristic of the J-phenomenon. This, of course, did not necessarily mean that the results had altered because the scatterer had been exposed to radiation for some time. It might have been due to one or more of many things:- scatterer, gold-leaf electroscopes, changes in the tube, etc., each of which could not be controlled by ordinary means. Such variations, therefore, could be associated, in the first instance, with changes in many different quantities. To test whether the change was due to the exposure of the scatterer, a different method had to be adopted. The original scatterer, showing the development from the sloping curve to the discontinuities, was one of 24 sheets of paper. Another scatterer of the same number of sheets was inserted in place of the first scatterer as soon as it was evident that the discontinuities were definitely established. A series of observations taken with this scatterer showed a slope for the initial filtering experiment curve, i.e. a curve similar to that obtained from the first observations with the original scatterer. In carrying out this experiment, the observations were made as quickly as possible after one another so that if there was any effect due to the exposure of the scatterer,/

scatterer, it would not have time to die away between the successive exposures necessary for each observation. It is reasonable to expect the effect to die away if there is such an effect due to exposure. Thus if the scatterer had been allowed to stand unexposed for some time, or if an interval had been allowed to elapse between readings, the curve would have been the normal curve such as would be given if exposure had no effect on the results. The fresh scatterer had also to be inserted as quickly as possible so that there would be very little chance of a change in the tube taking place in the interval required for the interchange of scatterers.



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The experiment was repeated time after time. Similar results were obtained. The slope changed slowly into the discontinuous curve although the period of experimenting required before the discontinuities finally developed was not always the same, even with the same scatterer and the same intensity of radiation incident on the scatterer. The position of the scatterers was kept, as far as possible, the same during the course of the experiments. On some occasions, the state of discontinuity was not reached in the course of the experiment, but when the change did occur, the progress from the slope to the discontinuous curve was as described above, and the introduction of a fresh scatterer, after the discontinuous state had been reached, gave an initial curve similar to that obtained from the first series of observations with the original scatterer. A new scatterer was not inserted on every occasion when development was observed but since one was inserted on at least fifteen occasions, it is improbable that the current through the tube changed each time during the very period in which the interchange of scatterers was being made. Such a happening could not but be dismissed as an almost incredible coincidence.

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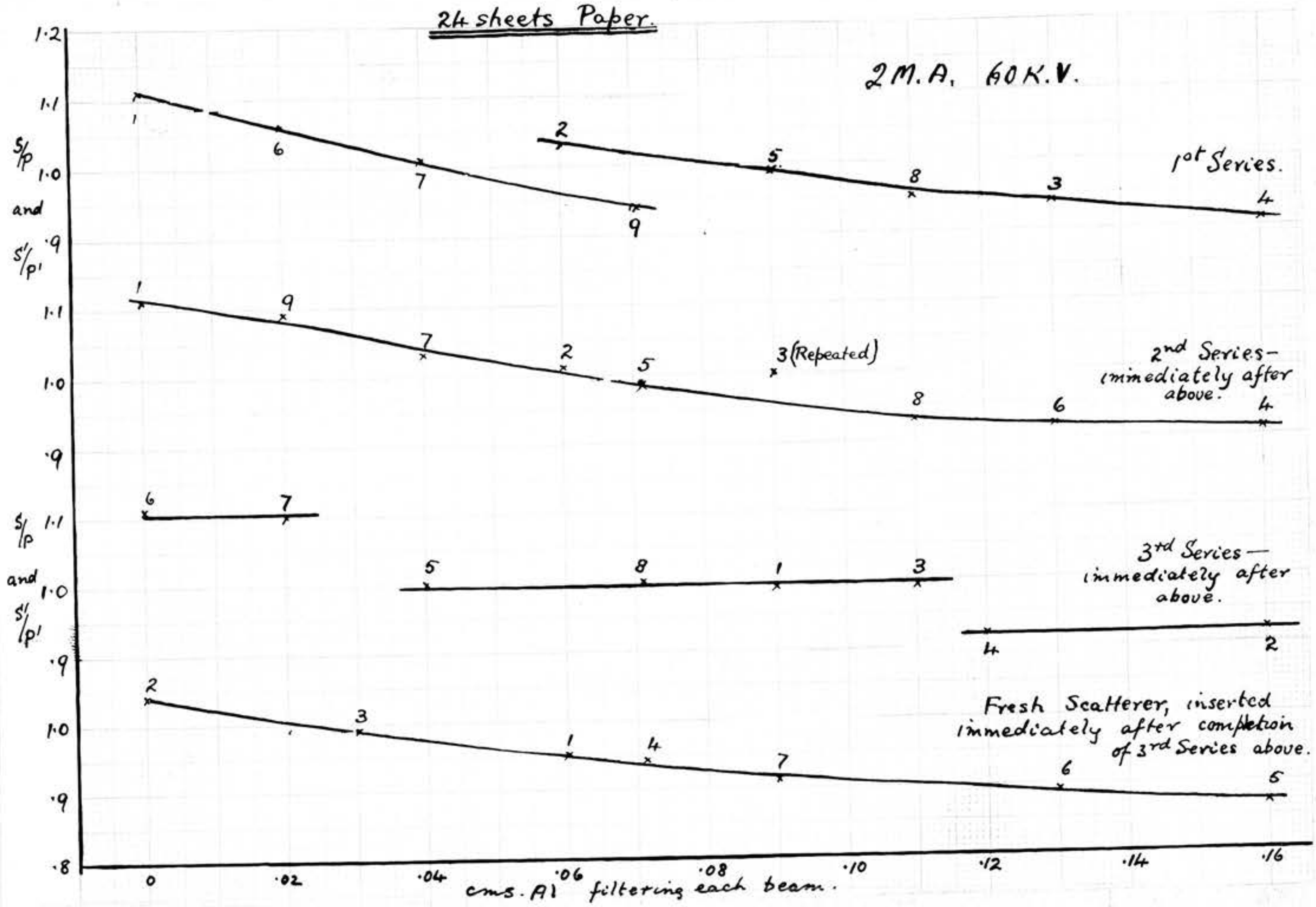
These experiments were, in the first instance made on radiation from the COOLIDGE tube. They were repeated sufficiently often to exclude the possibility that they might be accidental or erroneous. There still remained the possibility that the development might be due to or affected by, the nature of the source of the X-radiation. Results given by the radiation from one type of tube might not be obtained when using the radiation from another type of tube. For this reason, therefore, when the MÜLLER tube was inserted in the place of the COOLIDGE Tube, the experiments above were repeated so that there would be no doubt that the results were independent of the source of radiation. The radiation was, of course, still heterogeneous although rather harder than the radiation used in the earlier part of the research. The current through the tube could be increased beyond the limit possible with the COOLIDGE Tube and thus a greater intensity of incident radiation was possible.

Scatterers of 24 sheets of paper were again tested to find if the development would take place as before. The same development from slope to discontinuities was observed, the insertion of a fresh scatterer again showing the return to the continuous slope.



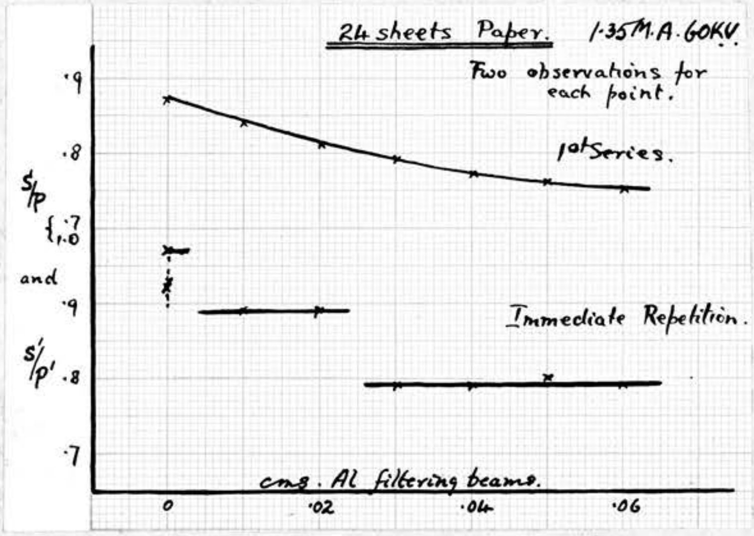
The results obtained were capable of much greater accuracy than was possible with the COOLIDGE Tube. Although it now seemed fairly definite that exposure had an effect on the result of a filtering experiment, one possibility yet remained, a very slight one no doubt. The current through the tube might be taken as remaining steady but changes might take place in the measuring apparatus, electroscopes etc., during the interval required to interchange the scatterers, expecially if that interval were long. Since no change appeared to be occurring in the dis-continuous/

discontinuous curve during the interval usually taken between readings, the new scatterer had to be inserted, so that the interval between the last observation for the first scatterer and the first observation with the second scatterer was the same as the usual interval between observations. Even when this was done, the curve obtained showed the change from the discontinuous curve of the first scatterer to a slope.

In a large number of experiments, when either one tube or the other was used as the source of the X-radiation, no fresh scatterer was introduced but the development from the slope to the discontinuities was unmistakable. In these experiments, as already mentioned above, the ratio s'/p' corresponding to a given thickness of Aluminium filter in each beam was observed once only for each thickness in each filtering curve. To lessen the possibility of an error arising due to these single readings, a series of experiments was made in which the value of s'/p' for a given thickness was observed a number of times before another thickness was inserted. The curves obtained from the majority of these experiments were very irregular, showing neither the slope or the discontinuities. This could be easily explained since each curve would contain points from observations of which some would be made while the

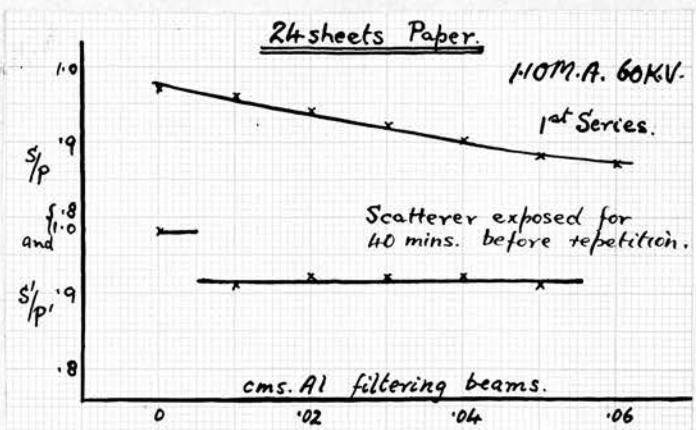
sloping/

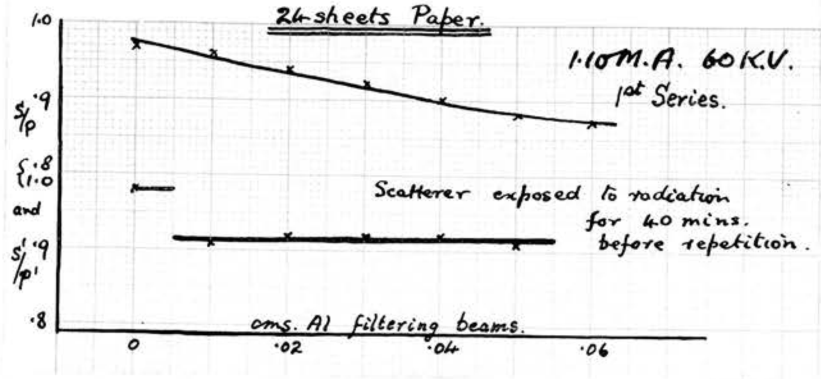
sloping curve was being obtained and others would be made while the curve obtained was the discontinuous curve. In a few of the experiments, a slope was obtained initially, this later changing suddenly, in the next test, into the discontinuities. The curves given show what is meant.

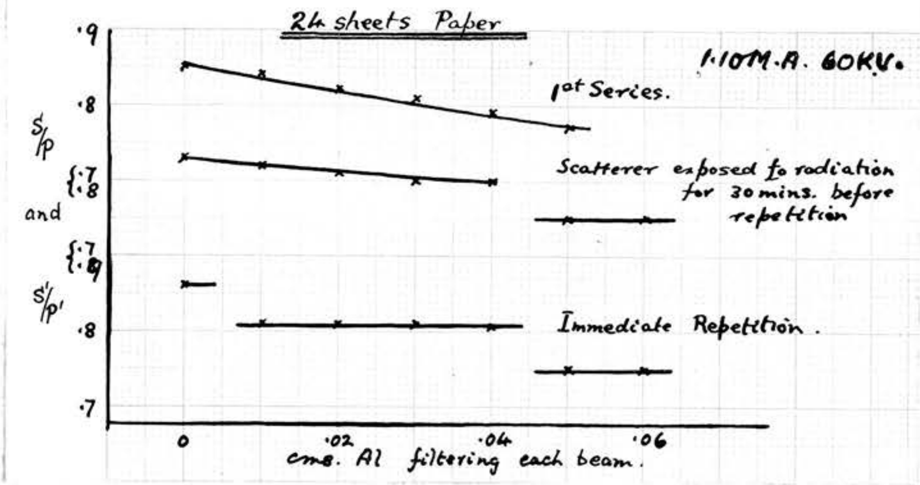


Other experiments were carried out but, in them, the scatterer was not exposed in quite the same way as in the above experiments. after the first series of observations had been made, the scatterer was exposed to a continual stream of radiation from the tube, the scatterer being kept in the normal position during the exposure. The absorbing sheets of aluminium were removed and the apertures blocked by sheets of lead, so that the electroscopes were not exposed to radiation during this exposure. Thus if a change from the slope to the discontinuities were/

were observed, the change could not be due to changes in the electroscope because of continued exposure; the change would seem in that case to be due entirely to the exposure of the scatterer, since the possibility of its being due to a change in the tube has already been considered unlikely. This method of experiment certainly showed the change from one type of result to the other, in seven of the ten experiments in which it was used. Also, when another scatterer, of an equal number of sheets of paper, was inserted in place of the first scatterer, the initial curve, a slope, was similar to that obtained initially with the first scatterer, differing from it only in the actual value of the ratios s'/p' for equal thicknesses of filtering Aluminium. On further exposure of this second scatterer, under the same conditions as obtained in the exposure of the first scatterer, the results changed in the usual way, i.e. in much the same way as observed for the first scatterer and in almost the same interval of time.

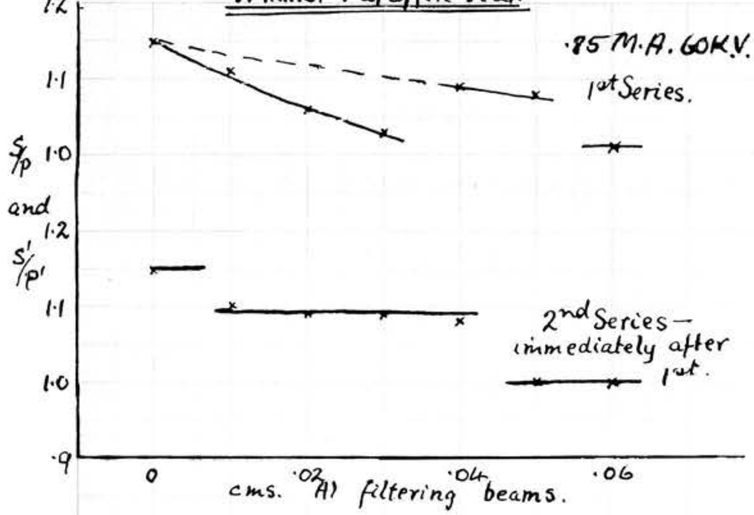




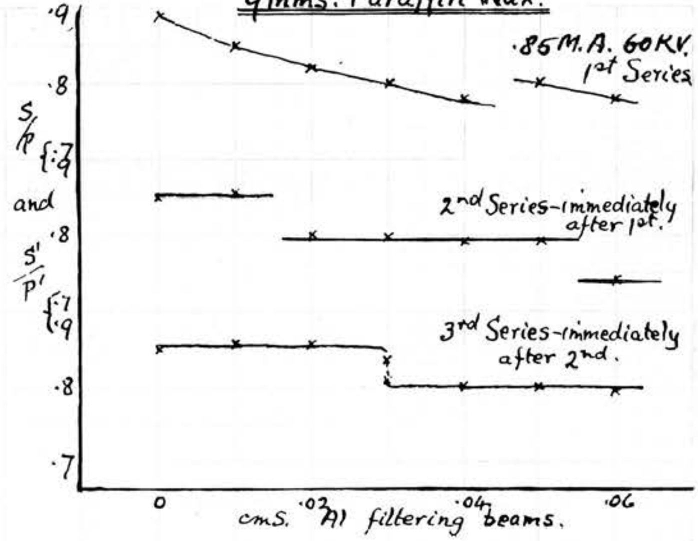


This seemed almost conclusive evidence that the change was due to the exposure of the scatterer and that the rest of the apparatus had no effect on the results. This, however, had to be tested further in order to find whether scatterers of other material than paper would give results similar/

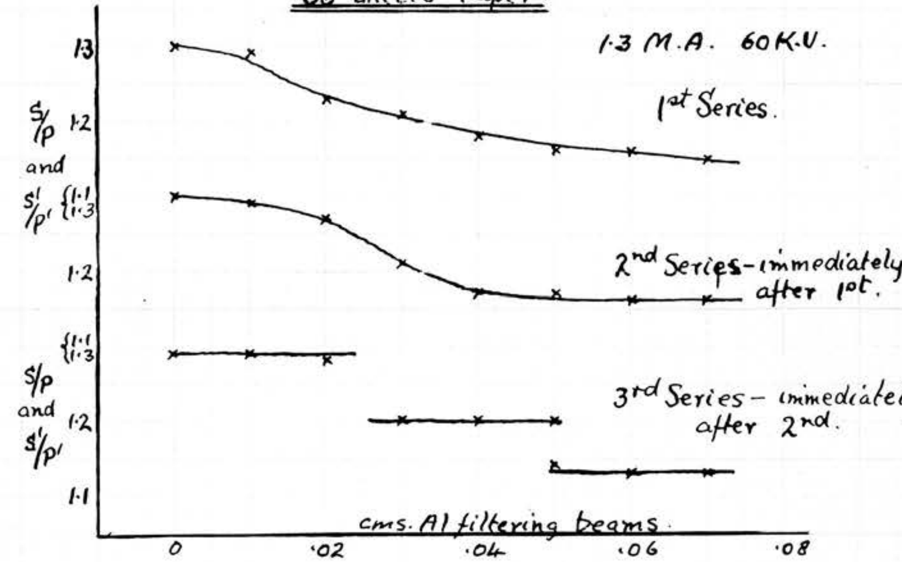
11 mms. Paraffin Wax



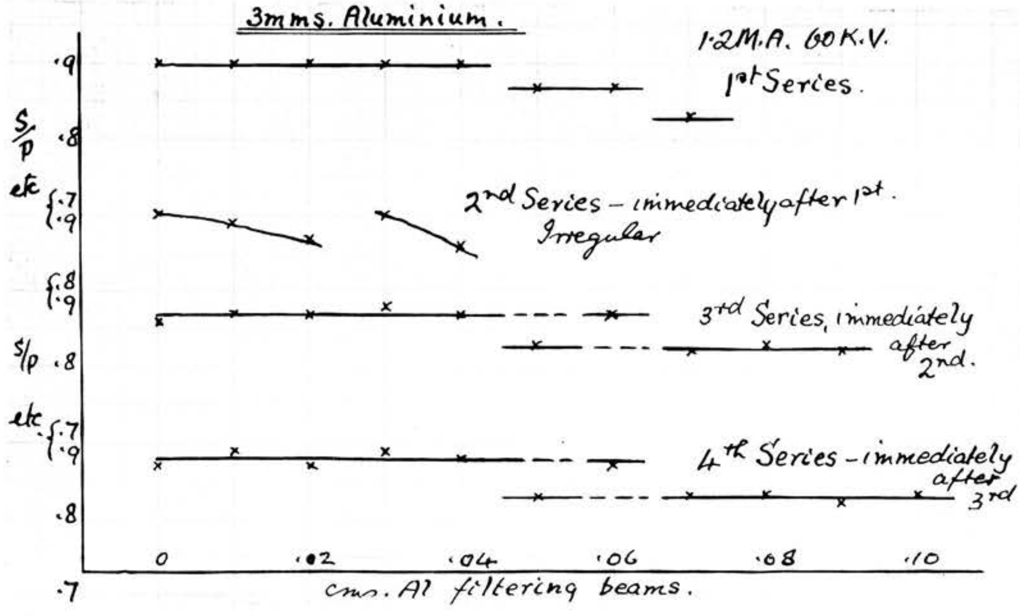
9 mms. Paraffin Wax.



36 sheets Paper.



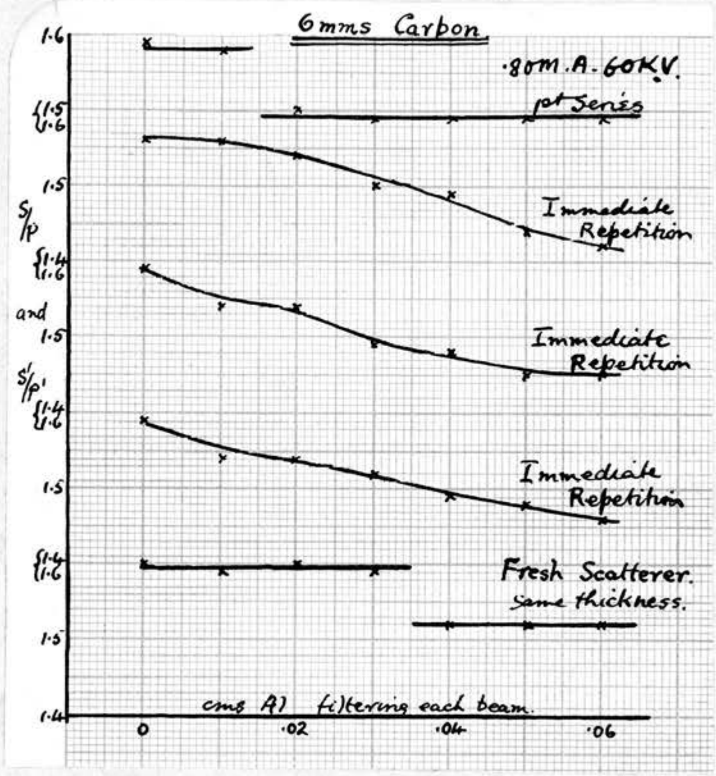
3mms. Aluminium.



similar to those obtained when paper was used. To this end, tests were made on scatterers of paraffin wax, carbon, plywood, aluminium and on paper scatterers composed of a larger number of sheets than had been used proviously. These tests were carried out using the same method as had originally been used; i.e. one series of observations was taken after the other was completed, no appreciable interval being made between the different series. The results of these showed that all the substances used, with the solitary exception of the plywood scatterer, give evidence of a change from one type of result to another. Irregularities certainly were evident in the later curves obtained in the filtering experiments using the plywood scatterer but they could not be allied definitely with the change sought. There was no tendency for the curves from plywood to become entirely discontinuous. Paper and paraffin wax showed the development very readily, while aluminium, giving initially, as it seemed, discontinuities, later gave as the result of filtering experiments a different type of discontinuous curve as shown in the curves opposite. Because of greater absorption of the incident radiation in the aluminium scatterer, the radiation entering the electroscopes in experiments/

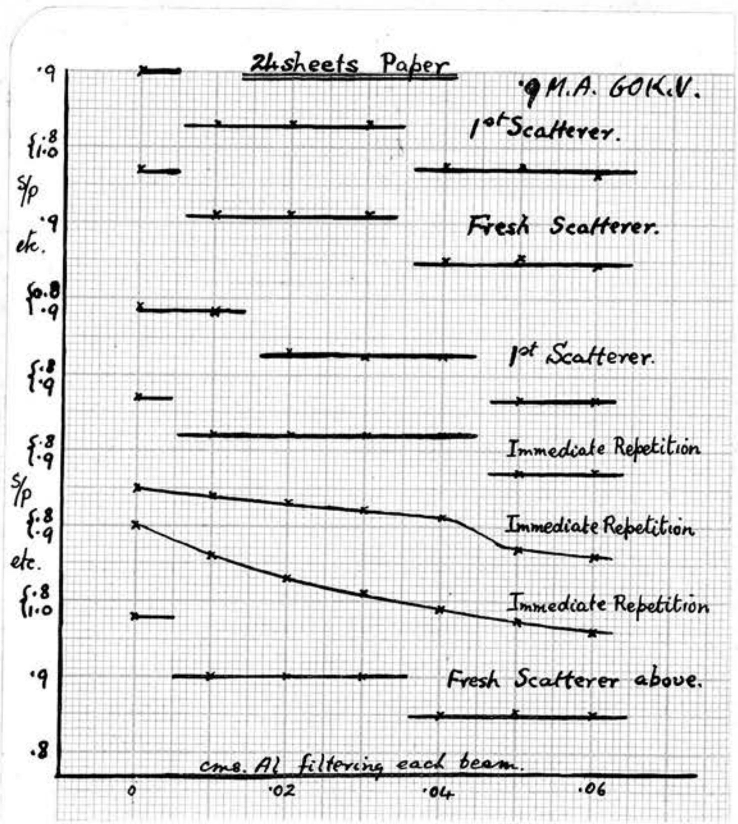
experiments with this scatterer was much harder than was the case in experiments on the other substances. It will be observed from the curves that there is quite definitely some development from the first series of observations with a given scatterer to the last series of observations with the same scatterer, the change being along similar lines for each i.e. from the initial slope to the final discontinuities.

So faf the results had been coherent and agreed among themselves. Experiments on this seeming exposure-effect gave rather unexpected results when 6 mms. thick carbon slabs were used as scatterers. These, used in the same way as scatterers of 24 sheets of paper had been used, gave, as the result of the initial filtering experiment, discontinuities and thereafter, the curves resulting from observations changed slowly into a continuous slope. On one scatterer, which had thus shown the development, being replaced, as quickly as possible, by another similar scatterer, previously unexposed, the result of successive filtering experiments with the new scatterer was to show a similar development from the discontinuities to the slope. Such a result was also obtained with scatterers of 24 sheets of filter paper.



Two scatterers of 24 sheets of filter paper were prepared, and used in separate consecutive experiments on filtering. Both experiments yielded the discontinuous filtering curve. The one which had been used first was re-inserted in place of the other and again a filtering experiment showed the discontinuities. On repeating the filtering experiment, time and again, with this scatterer, the curves obtained/

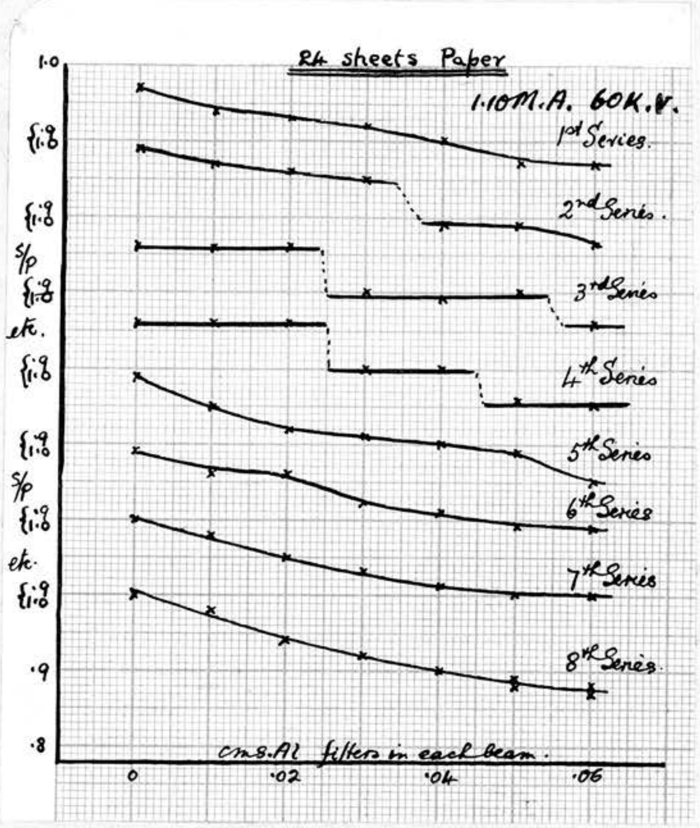
obtained gradually changed into a continuous slope. On the other scatterer being inserted in place of the one now showing the slope, a filtering experiment gave a curve showing the J-discontinuities. This reverse effect was observed in fifteen experiments in which different scattering substances were used, but chiefly occurred when carbon scatterers of 6 m.m. thickness were used.



Thus/

Thus it seemed that the previous results and all that could be deduced from them, had suffered a complete reversal. In one set of experiments, the gradual change in $^{s'}/_{p}$ with the thickness of the aluminium filters developed gradually into the discontinuous levels of equality in which $^{s'}/_{p}$ remained constant for a given range of thickness of aluminium filters and suddenly fell to a lower value for a succeeding range of thickness of the filters. In the next set of experiments exactly the reverse development occurred. Thus equally reliable experiments gave contradictory results. Which of these results was the correct one? Or were they both possible?

The answer was provided when a scatterer of 24 sheets of filter paper, giving a slope as the curve of its initial filtering experiment, was used in a large number of successive filtering exposures, even after the J-discontinuities had appeared on exposure. This prolonged use of the scatterer finally showed that the discontinuities disappeared and that the gradual slope had reappeared. This was repeated some fourteen times and the same result obtained. The appended curves show the type of development.

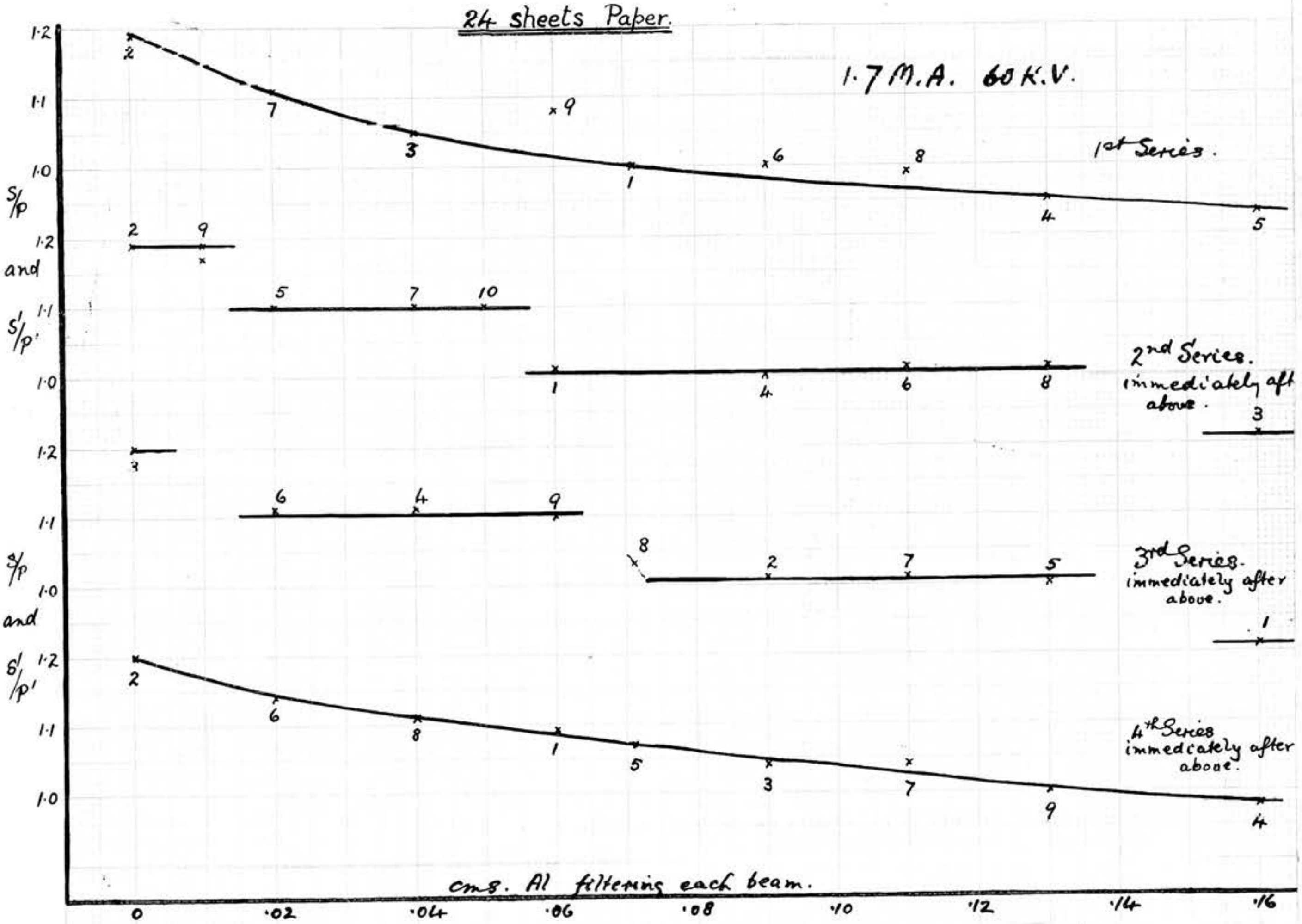


The curves may be compared with these obtained by BARKLA and MACKENZIE*, in filtering experiments, during which they changed the frequency of the interrupter attached to the induction coil by which the tube potential was supplied. (The writer does not mean that the development in the curves by ⋆ BARKLA and MACKENZIE was due to the effect now studied but the curves are of similar type). A similar change from the slope of the initial curve to the discontinuities and then back to the slope on further exposure

* Phil. Mag. Nov. 1926

⋆ The curves by these authors could be repeated by returning to a particular frequency of the interrupter.

exposure was observed in experiments in which the radiation was obtained from the MÜLLER tube. Thus it seemed that the development from one type of result to the other was due to the continued exposure of the scattering material.



It/

It can be observed from the curves obtained in the experiments in which the source of the incident radiation was the MÜLLER tube, that, when a change occurred in the type of result given by a filtering experiment in which the thickness of the aluminium filters was varied irregularly, the earlier observations gave points lying on a continuous slope, the later observations of the same series did not give points lying on the slope but gave points which, by their position on the graph of the results suggested the appearance of the J-discontinuities. The presence of the discontinuities was always shown quite definitely in the curve for the next series of observations.

Thus an explanation of these seemingly incompatible results was offered. The type of initial result for a filtering experiment with a given scatterer was controlled by the type of scatterer, by the state of the scatterer or its previous history as regards exposure to X-radiation. And from this, the later development of the curves obtained from successive filtering experiments agreed with the sequence described above.

Throughout this discussion of what the writer has termed the "exposure-effect" of X-rays on the scattering material, mention has been made chiefly/

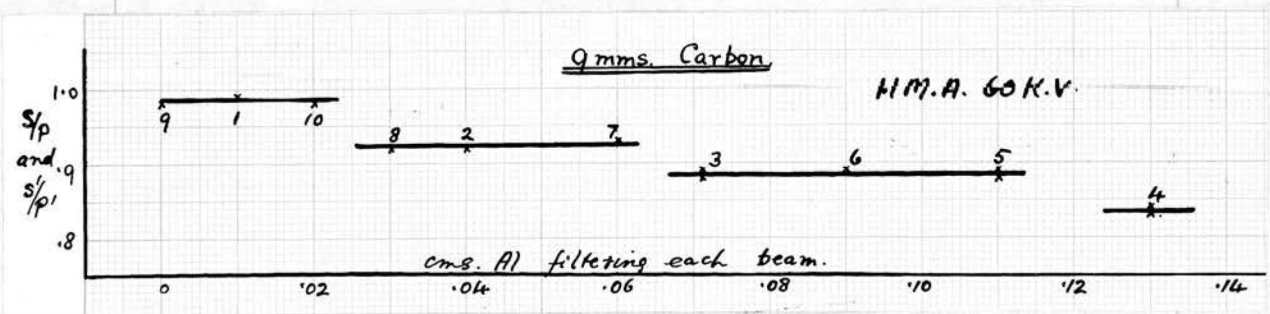
chiefly of scatterers of 24 sheets of paper. These scatterers were used almost exclusively during the earlier part of the investigation of the phenomenon of change from one type of result to another, because it was observed quite early that the change was given most readily by this type of scatterer, and as the reason for this change was being sought, it was most convenient to use a type of scatterer which would give the change most readily.

A short digression can now be made to discuss the results of filtering experiments in which the scattering material was carbon. The scatterers in these experiments did not consist of a single block of the carbon. As this could only be obtained in pieces 6 inches by 3 inches, two such pieces were placed together to give a suitable slab, 6 inches square. The edges of each block, which met in the centre of the scatterer, met as closely as possible and the gap between them was made as small as possible. The results of filtering experiments using this type of scatterer agree with the general results obtained when filter paper scatterers were used in similar experiments.

The general type of result obtained from experiments using a carbon scatterer, 6 m.ms. thick, has/

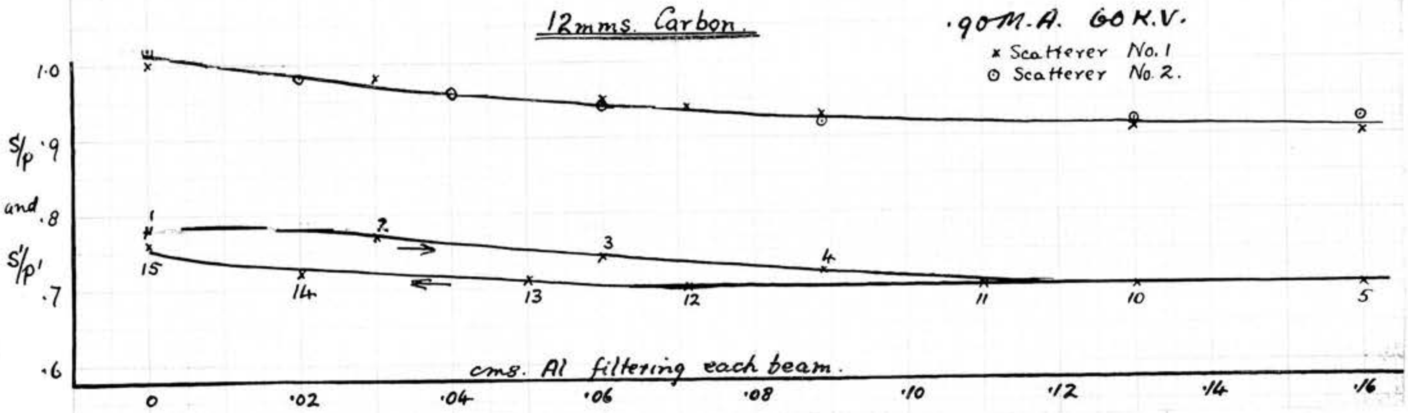
has been shown above. The initial observations gave evidence of the discontinuities while later series of observations gave filtering curves passing gradually into the continuous slope. When two scatterers of this type were used in consecutive series of experiments, one gave results showing the discontinuities over a longer period of time than the other. With both, there was no possible doubt of the gradual appearance of the smooth slope on exposure.

With Carbon of 9 m.ms. thickness, the discontinuities were again observed initially, but continued over the period of the experiment.

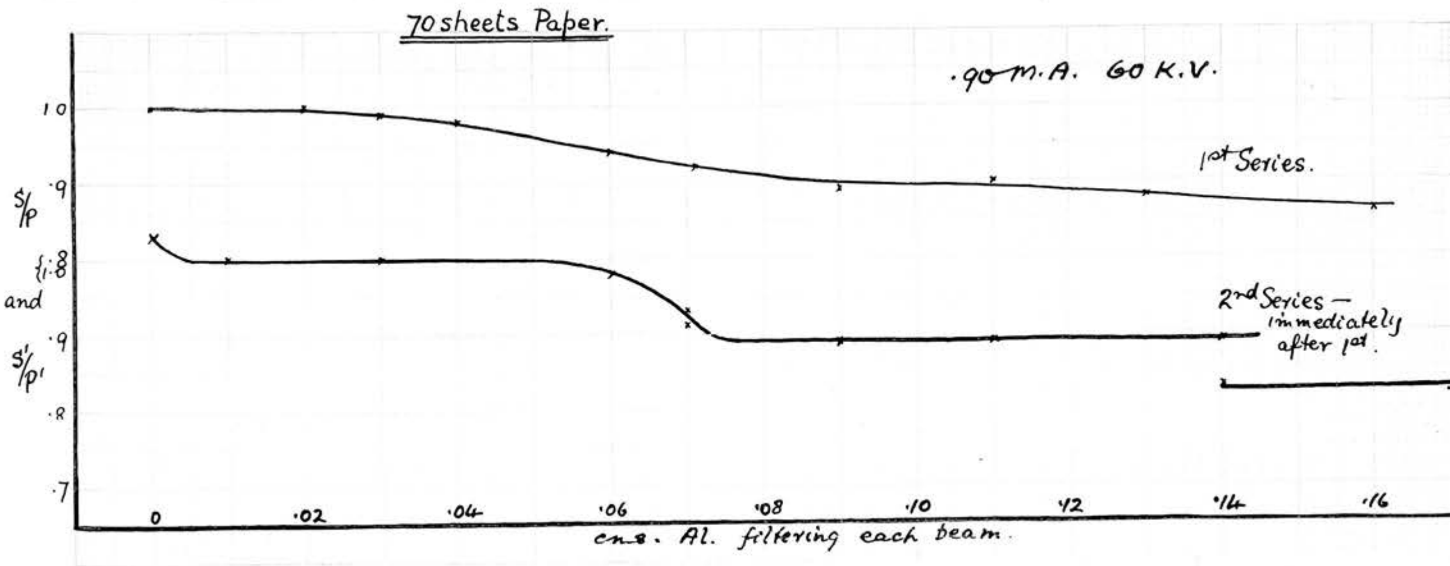


Scatterers of carbon, 12 mms. thick were also used in these filtering experiments, with a view to testing whether the nature of the excitation of the tube or the type of measuring apparatus had any effect on the nature of the results obtained. These tests were made in conjunction with Mr. James Paton, M.A., B.Sc., also of this Laboratory. In them, the variaable/

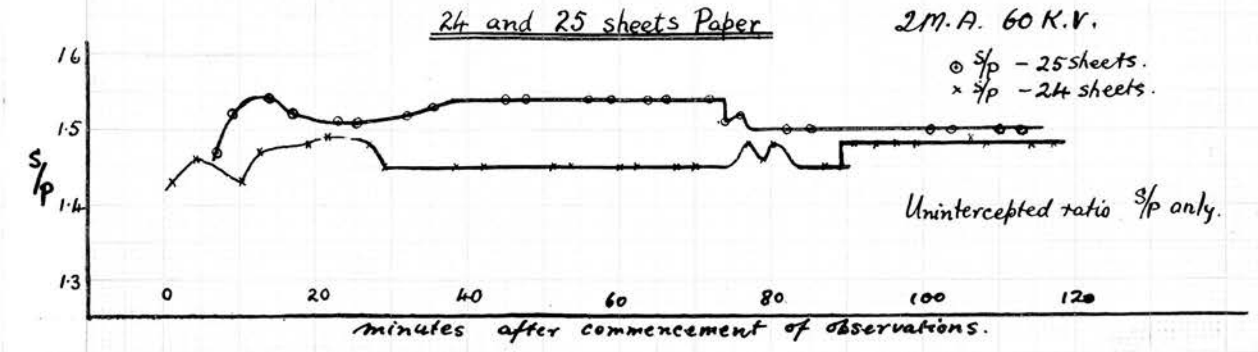
variable initial result was observed by the writer, once only, the final curve in this and all other cases, being a continuous slope, more or less regular. The slopes obtained in the filtering experiments by Mr. Paton, using a transformer fitted with auto-transformer supplied directly with A.C. from the town mains as his source of potential, were almost identical with those obtained in the experiments by the writer. The tube used by Mr. Paton, was an ordinary type COOLIDGE tube with Tungsten Anticathode. The secondary beam was passed into an ionisation chamber attached to a WILSON tilted electroscope, and the primary beam into a cubical gold-leaf electroscope. The experiments were made on two carbon scatterers of equal thickness, each experimenter using one over a long range of absorbing sheets of Aluminium used as filters and then exchanging the scatterers. The curves for each scatterer were observed to be slightly different but the curves for each experimenter agreed within the limits of error. In some of these tests, it was observed that the ratio $^{s'}/_{p'}$ remained constant over a range of filtering aluminium, as in the curve shown below, the range of constancy very nearly coinciding in the curves obtained by each experimenter.

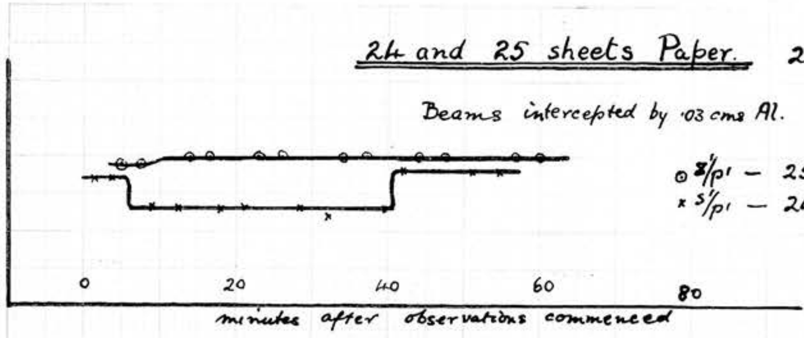


Scatterers containing 70 sheets of paper were also tested to find whether the filtering curves obtained in a series of experiments varied from the slope to the discontinuities as had been observed with 24 sheets. A similar progress was shown on the first days on which the 70 sheets were used. On later days, however, it was found that the slope was generally obtained, although it was more or less irregular.



In a series of experiments in which the incident radiation was obtained from the MÜLLER Tube, the number of sheets in the scatterer was changed, when desired, from twenty-four to twenty-five. The change was made quite readily as the scatterer of twenty-four sheets was kept fixed in position and the extra sheet placed alongside it or taken away as desired. In these experiments, the ratio s'/p, for the unintercepted beams, was measured for the scatterer of 24 sheets over a number of consecutive exposures, the extra sheet was then inserted and a similar number of exposures and observations made with the altered scatterer. A return was then made to the scatterer of 24 sheets and so on. The results, as shown by the curves below, are very interesting. It will be observed, that, after varying for a time, the ratio s/p for each scatterer became very nearly equal, then separate and finally return to their almost exact equality. Results of such experiments on scatterers of 24 and 25 sheets, when the ratio s'/p' was observed for each radiation when the beams were filtered through .03 cms. Aluminium, were of the same type but more definite. The sequence of observations is given on the figure plotted against the time.

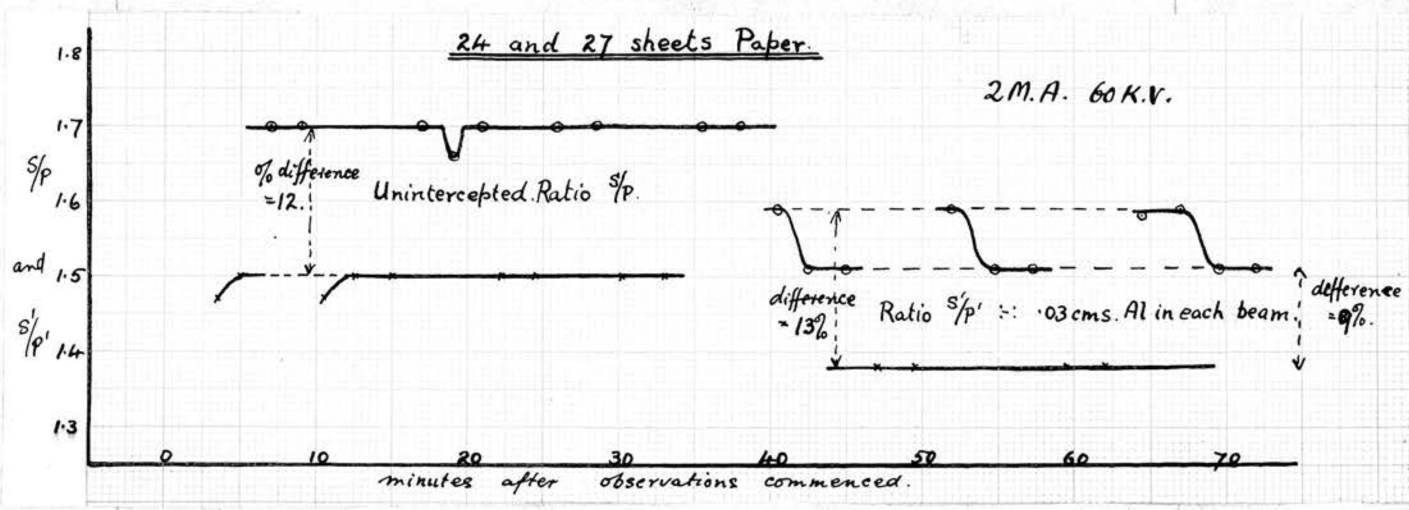




An exactly similar series of experiments was made on scatterers of 24 and 27 sheets. As above the scatterer of 24 sheets was kept fixed in position while the extra three sheets could be added or removed. The ratios measured were the unintercepted ratios $^{s}/_{p}$ and the ratios $^{s'}/_{p'}$ when .03 cms. Aluminium was inserted in each beam. The difference between the ratios $^{s}/_{p}$ for each beam was constant throughout the period of the experiment but the ratio $^{s'}/_{p'}$ varied thus.

(1) In each group of readings for $^{s'}/_{p'}$ when the scatterer consisted of 24 sheets, the ratio remained constant.

(2) In each group of readings for $^{s'}/_{p'}$ when the scatterer contained 27 sheets, the ratios vary from the initial value to a lower final value, the change from one value to the other, being approximately 5% and taking place suddenly as far as could be ascertained by the experimental method.



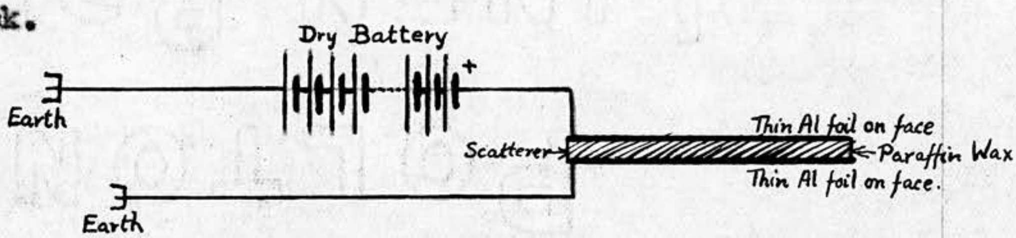
Thus the value of $^{s'}/_{p'}$ for 24 sheets differed from the initial value of the ratio $^{s'}/_{p'}$ for 27 sheets by 13% and from the final value of $^{s'}/_{p'}$ for 27 sheets by 8%, the change in the difference of the ratios taking place discontinuously. The ratio $^{s'}/_{p'}$ for 24 sheets in the scatterer was usually observed in these experiments to be constant during the experiment, while the value of the ratio $^{s'}/_{p'}$ for 27 sheets in the scatterer was generally observed to vary as indicated.

These/

again/
These variations show, in the writers opinion that the change in ratio was due to continued exposure of the scatterer. The scatterer of 24 sheets had become "inured" to the effect of the radiation while the extra three sheets had periodical exposures and intervals for recovery.

EXPERIMENTS OF SCATTERERS OF PARAFFIN WAX.

The Paraffin Wax scatterers were initially introduced in an attempt to test whether the type of result obtained in filtering experiments would be affected by the presence of an electrostatic field across the scatterer; this being an attempt to produce in the scatterer an effect somewhat similar to that obtaining when the molecules are in an ionised state. In order to obtain the required electrostatic field, the opposite faces of a slab of paraffin wax, 19 mms. thick, were covered by thin Aluminium foil, .001 cms. thick.



Method used to charge Scatterer.

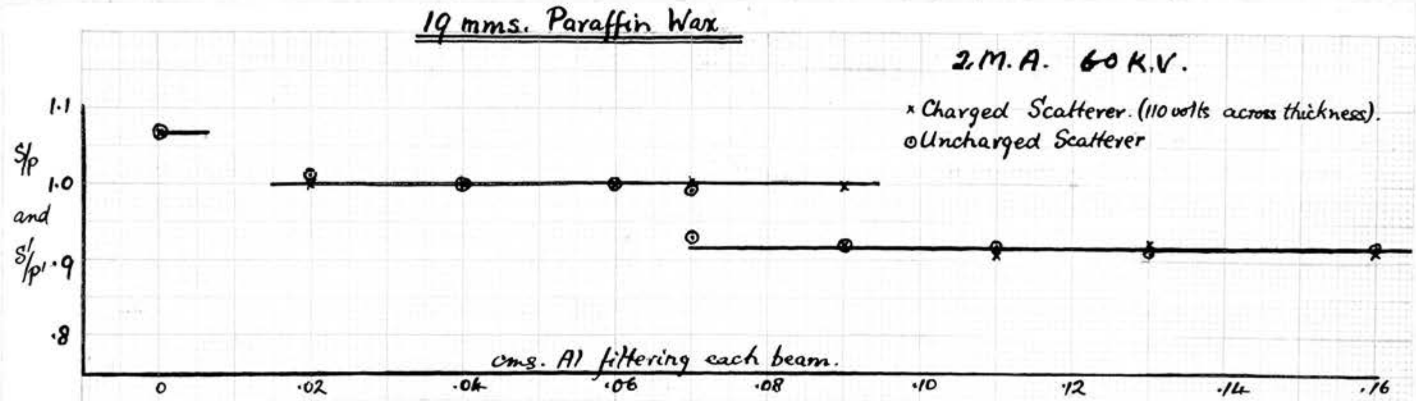
Connections were made from the corners of these sheets to a battery of dry cells as shown in the diagram, the slab being placed on a piece of ebonite for insulation purposes. Thus one face of the slab was earth connected while the other opposite face was at a potential of 110 volts. When filtering experiments were made, no difference could be observed between the results obtained -

(a)/

(a) when the scatterer was "charged"

and (b) when the scatterer was "uncharged".

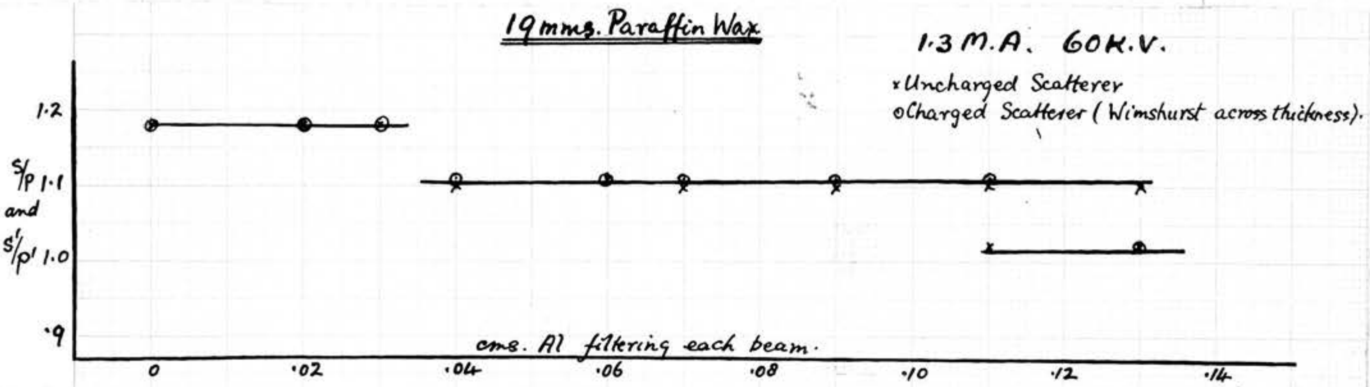
In fact, the curves below, obtained from these experiments, could be almost exactly superposed. The value $^{s'}/_{p'}$ for a given thickness of Aluminium in the filters was observed first for the "uncharged" scatterer and next for the charged scatterer before the value for another thickness was observed. Five experiments of this type were made and all gave a similar result.



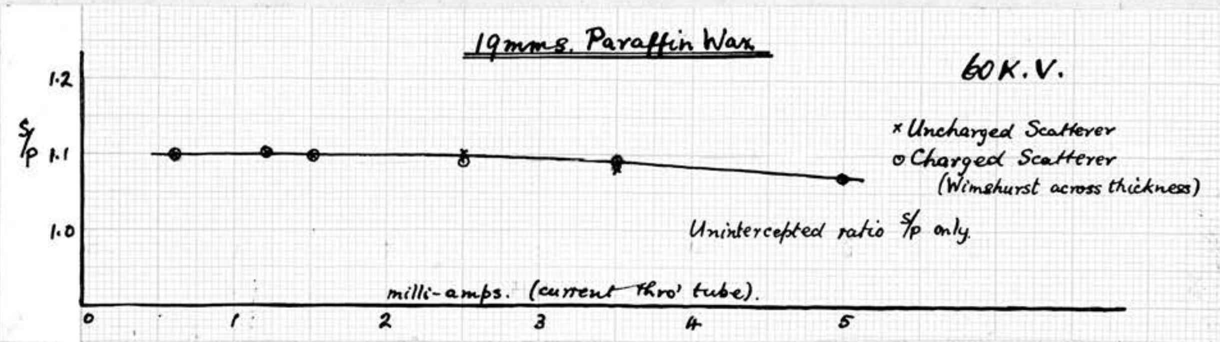
It will be observed from the curves inserted that there is no definite dissimilarity in the results for the scatterer in the different states. Since the observations were made alternately for each state, there is no possibility of a change having taken place during the experiment and of its being observed in one experimental curve and not in the other.

That/

That no difference in the type of result was observed in the above experiments might have been due to the potential difference across the scatterer not being sufficiently large. The potential difference was increased by replacing the dry battery by a WIMSHURST Machine. The machine was worked continuously during an observation of $^{s'}/_{p'}$ for the "charged" scatterer. It was then discharged and the observation made for the "uncharged" scatterer. Once again no change was observed in the type of result. The paraffin wax absorbed a great amount of charge in these experiments



While the experiments were being made on the "charged" and "uncharged" scatterers, changes were made in the current through the tube and the ratio for intercepted radiations observed for the respective scatterers in the same way as before. The values of $^{s'}/_{p'}$ thus obtained for each scatterer showed no divergence. This can be seen from the curve below.



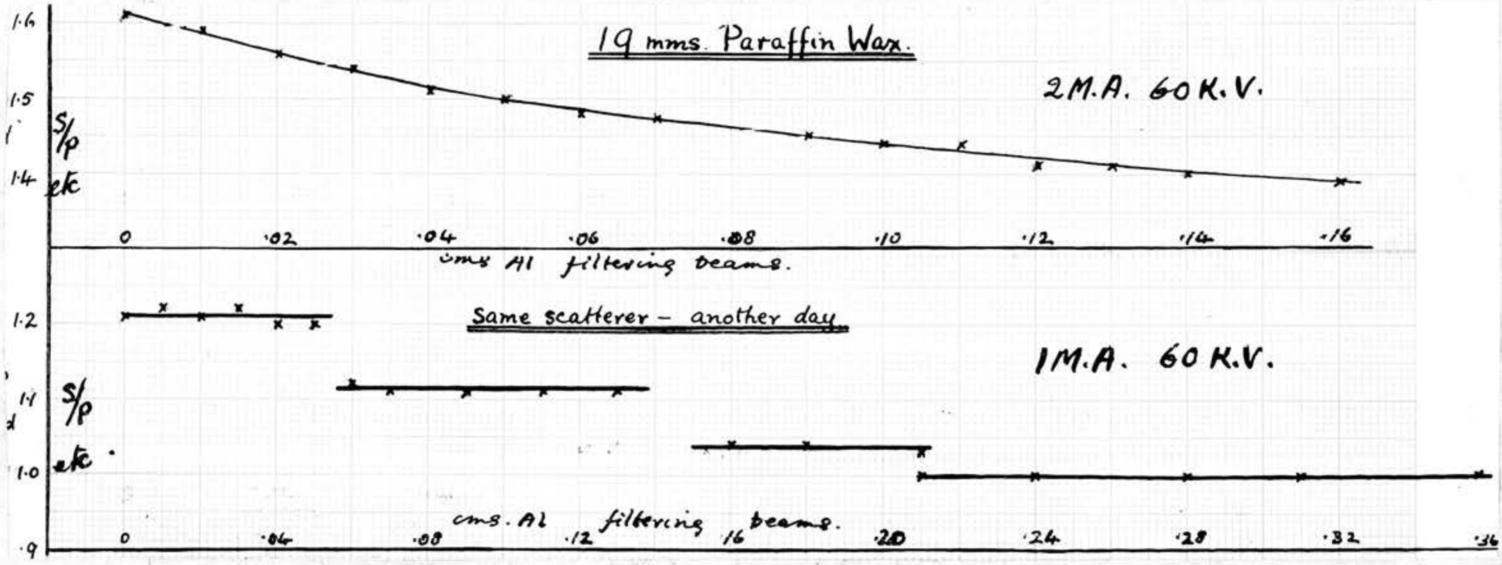
Thus charging the scatterer seems to have no effect on the type of result, at least when the filtering curve obtained from the "uncharged" scatterer is a discontinuous one.

The paraffin wax scatterer, introduced above, was used in a series of experiments which lasted over a period of nearly five months. During the first three months, discontinuities appeared in the filtering curves in 85% of the experiments made. During the next month, continuous curves and discontinuities appeared in almost equal numbers. During the next month, the discontinuities again appeared regularly. There was no change in the arrangement of the apparatus in any way, as far as this could be ensured, during the period of the experiments. As shown by the following table of results, the periods were quite well-marked, as far as the type of result obtained in the experiments was concerned.

PERIOD	SLOPE	VARIABLE	DISCONTINUOUS CURVE.
Oct.14th 1930 to Jan 7th 1931	6 15%	0	34 85%
Jan 8th 1931 to Feb.11th 1931	7 41%	5 29%	5 29%
March 1931	0	0	5 100%
TOTALS	13 21%	5 8%	44 71%

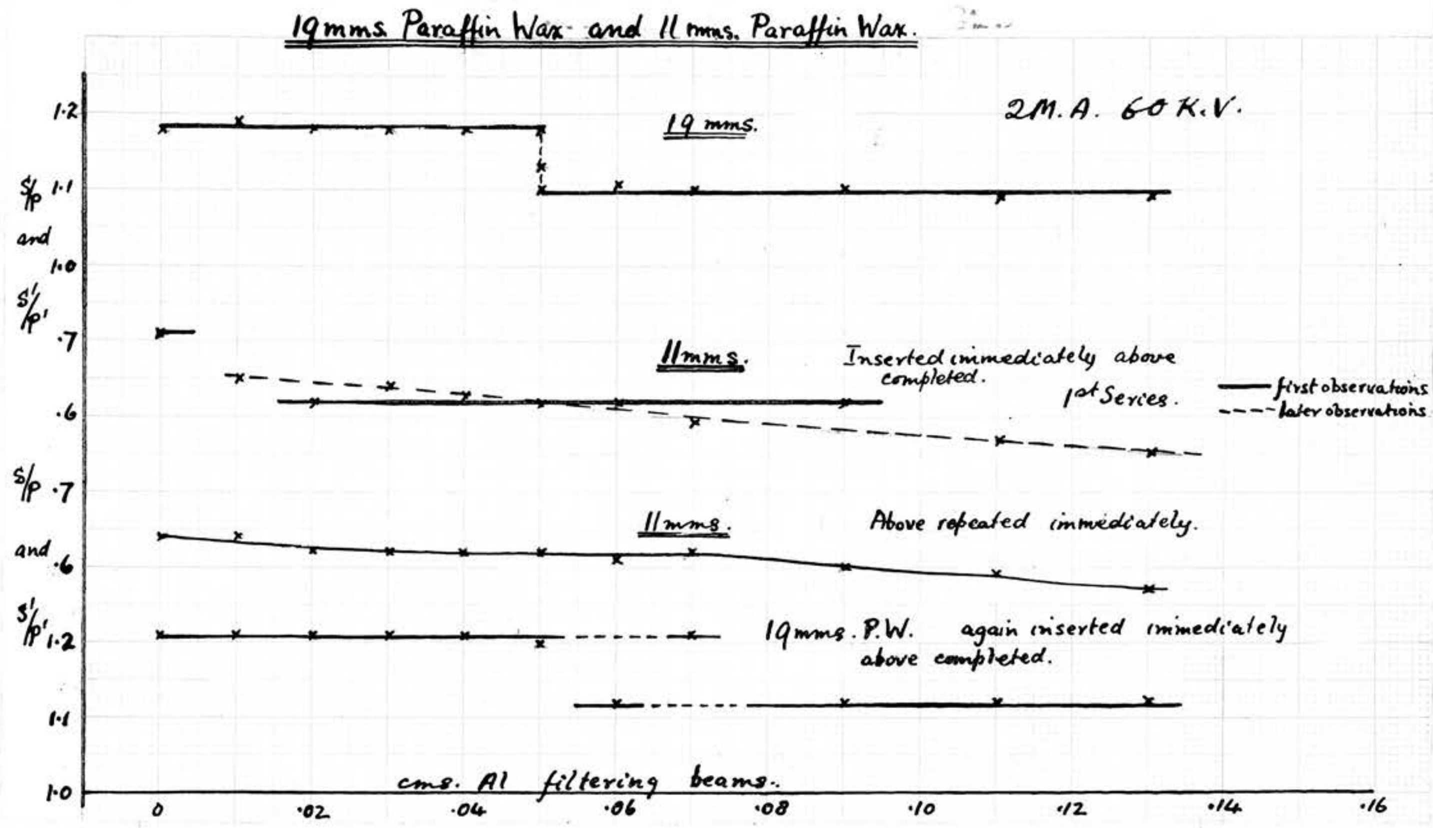
It will be observed from the above table of results that the number of cases in which discontinuities were observed outnumbered the cases in which slopes were obtained. The variable cases, amounting to five experiments out of sixty-two, were those giving curves consisting of levels of equality joined by sloping sections, making the whole curve continuous though not regular. The continuous and discontinuous curves were of the type shown below and remained of this type during the series of experiments. The discontinuous type of curve is rather/

rather unexpected when the scatterer is as thick as the one used in these experiments.



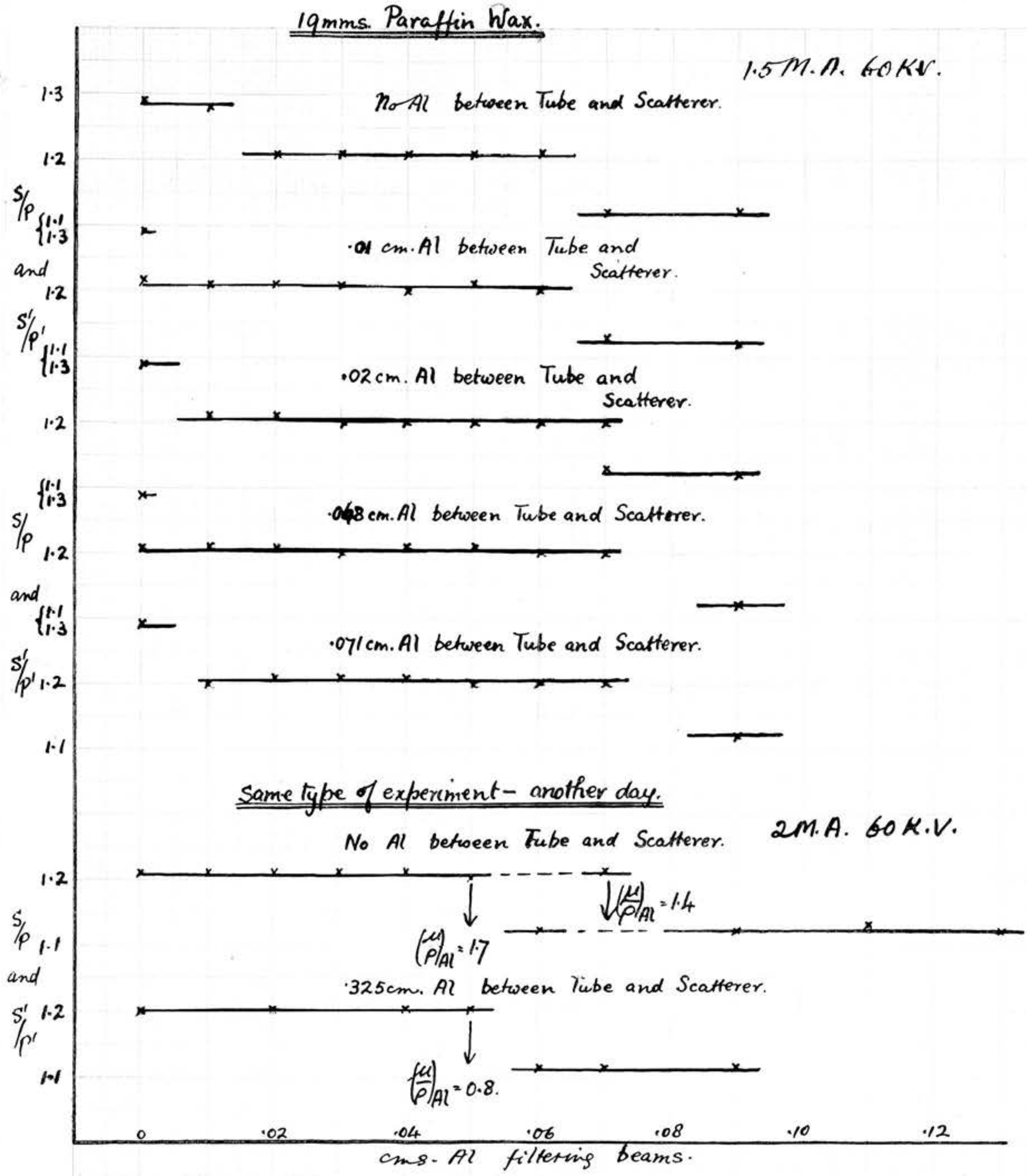
During the series of experiments, the results of which are recorded above, slight variations were made in the method to test whether changes in the conditions would alter the type of curve or the positions of the discontinuities.

A scatterer of paraffin wax, 11 mms. thick, was inserted in place of the scatterer, 19 mms. thick when the discontinuities had become apparent. The new scatterer at first showed the presence of the discontinuities, but these later disappeared, and the curve obtained in a filtering experiment, was merely the continuous slope. Re-insertion of the thicker scatterer after the slope had become quite definite, again showed the presence of the discontinuities, at the same thickness of absorbing aluminium in each beam and at the same average hardness of the primary radiation as in the first exposure.



Displacement of the position of the discontinuity was attempted by hardening the beam falling on the scatterer. This was done, as before, by placing filters of aluminium in the path of the radiation. It was observed that the position of the discontinuity did not vary appreciably even for a very considerable hardening of the beam incident on the scatterer. (There was a slight variation evident in some of the results, vide the curves below, but the variation was not a regular one). In the second group of the series of curves given below there was no apparent difference in the results of the two filtering experiments, except that the discontinuity,/

discontinuity, although it occurred for the same thickness of filtering aluminium in both, occurred at a different average hardness of the radiation used. This result is in agreement with the results of experiments showing the value of $^{s'}/_{p'}$ to be constant as the average hardness of the beam of X-rays is increased.

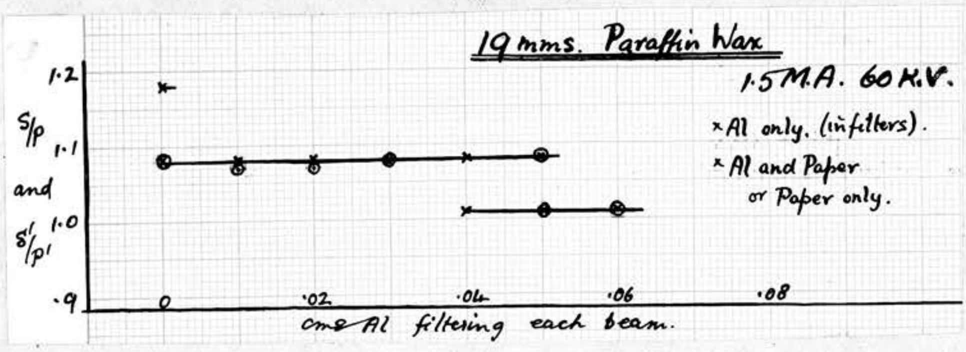


In some filtering experiments, when the dis continuities had been observed with a scatterer of Paraffin Wax, 19 mms. thick, attempts were made to continue the upper level of equality past the point of discontinuity. In these attempts, filters of filter paper were used in addition to the filters of aluminium. The method was as follows. Each thickness of filter paper inserted contained a sufficient number of sheets to reduce the intensity of the beam of radiation* by the same amount as .01 cm. Aluminium. To obtain the requisite number of sheets, .01 cm. Aluminium was inserted as a filter in the scattered beam, while the primary beam was kept unintercepted. The deflection of the leaf of the secondary electroscope was observed for a deflection of ten divisions in the leaf of the primary. Next, the aluminium was replaced by a number of sheets of paper and this number of sheets varied till the deflection of the leaf of the secondary electroscope corresponding to a deflection of ten divisions of the leaf of the primary electroscope was the same for paper and aluminium both. The equality of deflection was observed a number of times and by this means .01 cms. Aluminium seemed equivalent in absorbing power to 37 sheets paper.

When/

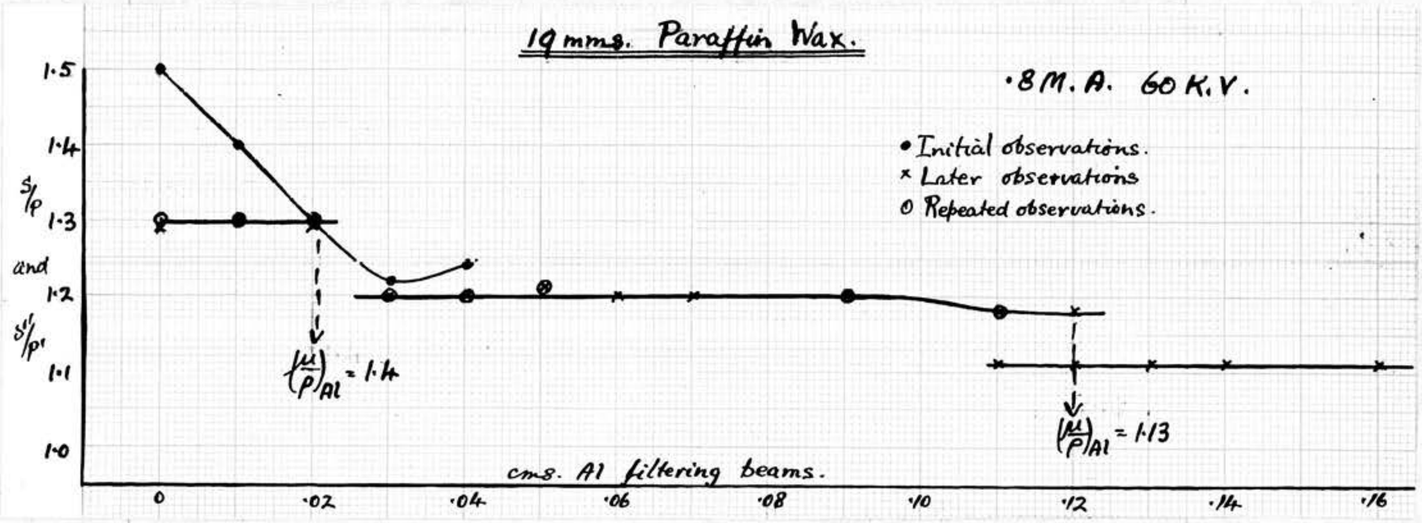
×* As measured by ionisation.

When a discontinuity was observed in the result of a filtering experiment, the point of discontinuity was carefully made definite by observing it time and again. The last sheet of .01 cm. Aluminium which could be inserted in each beam, without producing the discontinuity, was removed and 37 sheets of filter paper inserted in its stead. The ratio $^{s'}/_{p'}$, observed for such filters, was on the higher level, but, if another 37 sheets of paper were inserted in each beam, the ratio fell to the lower level and remained there for further increases in the thickness of the filters. This was verified time after time, the discontinuity occurring at the same point both for Aluminium and for Aluminium and paper combined, as shown by the curves below.

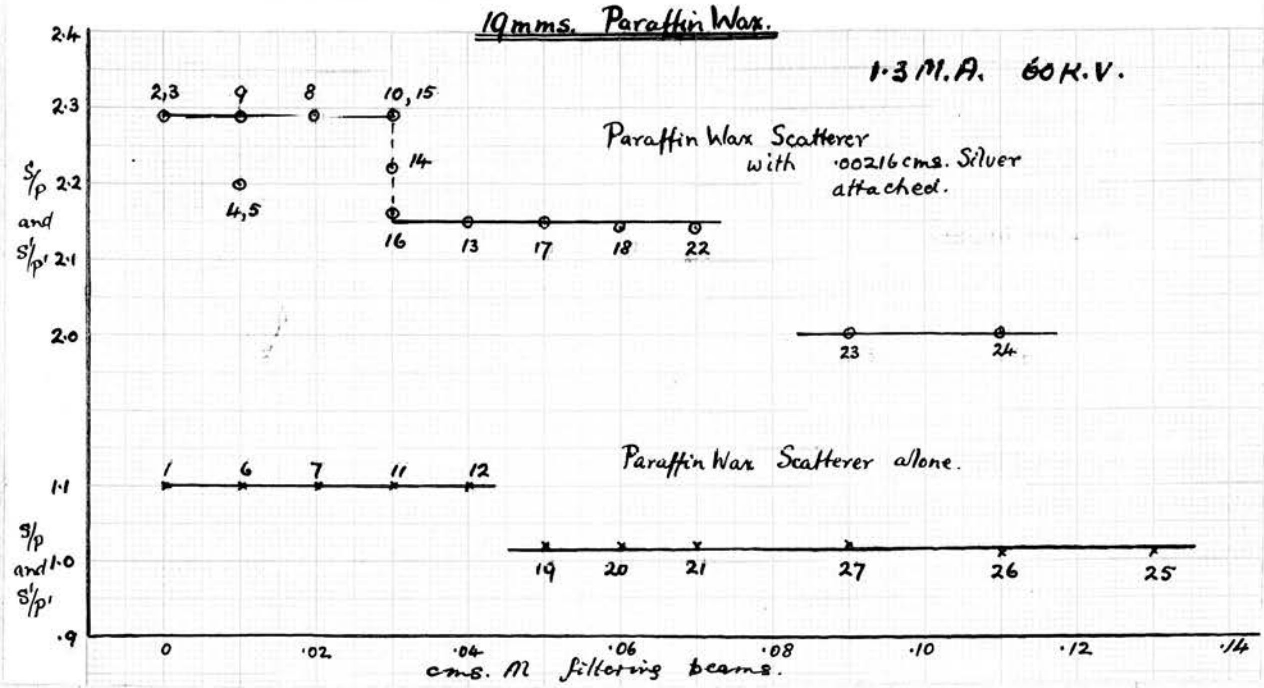


The transmitted and scattered beams were also compared in a series of experiments in which the back walls of the electroscopes were coated with gold-leaf./

gold-leaf. Thus a corpuscular radiation was superposed on the ionising radiation in the electroscope. The results were rather variable at times due to the possibility, though slight, of the beams wandering over the unevenly coated back walls of the electroscopes. In one of these experiments, a filtering curve showed a steady decrease of the ratio s'/p' with the thickness of the filters. In two other experiments of this type, discontinuities appeared. It will be observed from the curves obtained in these latter experiments, reproduced below, that the observed values of s'/p' seemed at first to show the presence of the characteristic radiation from gold, indicated by gradual increase and decrease of s'/p', but later, only the abrupt discontinuities of the J-phenomenon were evident. The hardnesses at which these discontinuities occurred were rather different from those previously measured in research on the J-phenomena, but the measurement of the hardness of the ionising radiation was rendered inaccurate by the ionisation produced inside the electroscopes by the radiation from the gold leaf on the electroscopes. This ionisation was not much reduced by the aluminium filters and so the estimate of the hardness of the beam was rendered inaccurate by the addition of the effect due to this ionisation.



In other experiments with paraffin wax scatterers, a sheet of silver (.00216 cms. thick) was placed alongside the scatterer of paraffin wax (19 mms. thick). Thus the radiation from the tube was incident on the silver and the paraffin wax and the emergent radiations, both primary and secondary, contained some of the characteristic radiations of silver. In these experiments, a return was made to the electroscopes used in the early part of the research. It was observed that the discontinuity, obtained with the paraffin wax alone, was not obtained when the silver was inserted, although the same type of discontinuous curve was obtained, as shown under, the discontinuities occurring at different places.



It will be evident from the curves above that the ratios $^{s'}/_{p'}$ observed when silver was added to the s catterer, were higher than the corresponding ratios for the paraffin wax alone. In order to ensûre that the results were observed under the same conditions of experiment, the two filtering experiments were inter-associated. The numbers attached to the points on the curves, show the order in which the points were observed. It will be seen that the silver was removed occasionally and reinserted after

a/

a few observations had been made with the paraffin wax alone. The silver was inserted in the same position on each occasion. To prevent any error due to slight changes in the position of the silver, the value of $^{s'}/_{p'}$ for a thickness of filter previously used was again observed to ensure that it had not altered. Thereafter the value of $^{s'}/_{p'}$ for other thicknesses of filter was observed. This method was repeated throughout the experiment, points being observed and re-observed occasionally. The experiment was repeated a few times and similar results obtained.

DISCONTINUITIES in the ABSORPTION CURVES of the PRIMARY and SECONDARY BEAMS.

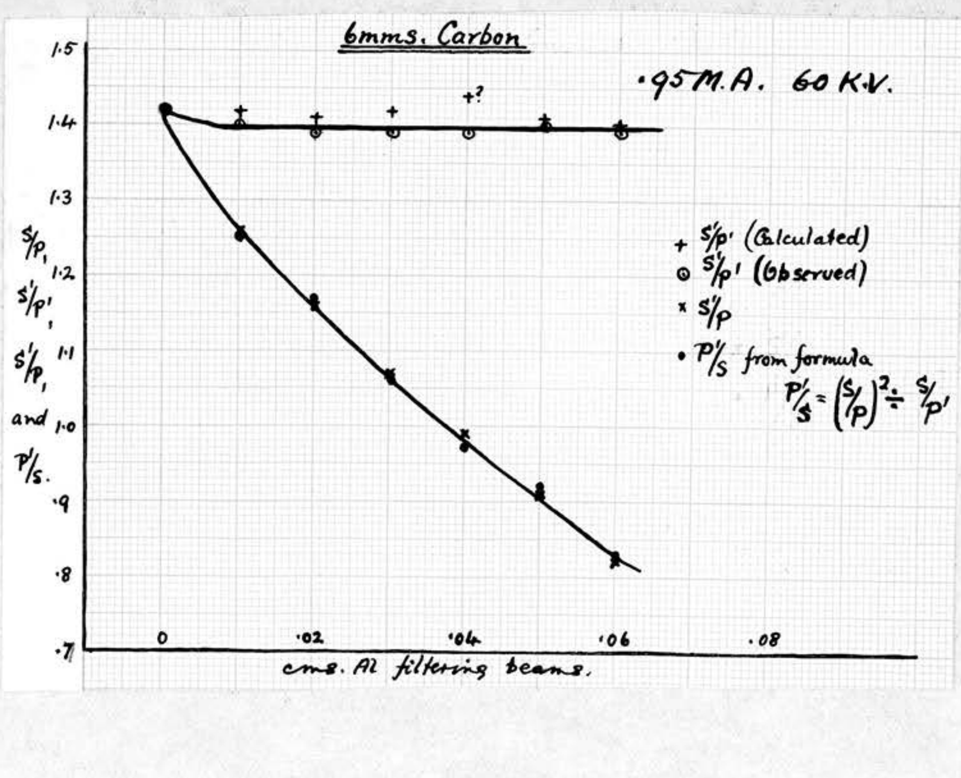
Each beam was tested for the presence of *discontinuities in absorption by aluminium. The beam tested was filtered by different thicknesses of aluminium while the other beam was kept unintercepted Thus what have been termed the ratios $^{s'}/_{p}$ and $^{p'}/_{s}$ were observed for varying thicknesses of Aluminium in the respective beams. In order to test the accuracy of the results, three different experiments were made during the same period. The ordinary filtering experiment in which $^{s'}/_{p'}$ was observed for equal thicknesses of aluminium in each beam was carried out during the period in which $^{s'}/_{p}$ and $^{p'}/_{s}$ were observed for aluminium in either the secondary beam or the primary beam. Thus the ratio $^{s'}/_{p'}$ was observed for x cms. aluminium in each beam; next $^{s'}/_{p}$ was observed for x cms. aluminium in the secondary beam and then $^{p'}/_{s}$ was observed for x cms. aluminium in the primary beam. Thus absorption curves were obtained independently/ for the two beams in addition to the ordinary filtering curve. An approximate value of $^{s'}/_{p'}$ for any given thickness, x cms., of aluminium in/

* Since in the previous experiments the discontinuity might have occurred in either beam.

in both beams was obtained from observed values $^s/_p$, $^{s'}/_p$ and $^{p'}/_s$ for x cms. aluminium in the requisite beams, from the formula, $(^{s'}/_{p'})_x = \dfrac{(^{s'}/_p)_x \times (^s/_{p'})_x}{^s/_p}$

Thus the observed and calculated results served as a slight check on one another.

The curve below was obtained when the COOLIDGE Tube was used and the scatterer was Carbon, 6 mms. thick. The calculated values of $^{s'}/_{p'}$ were fairly close approximations to the observed values. The graphical representation of the variation of the ratios $^{s'}/_p$ and $^{p'}/_s$ with thickness of aluminium, showed that, while no discontinuity was observed in the experiment, the ratios decreased at the same rate, showing that the beams were equally absorbable.

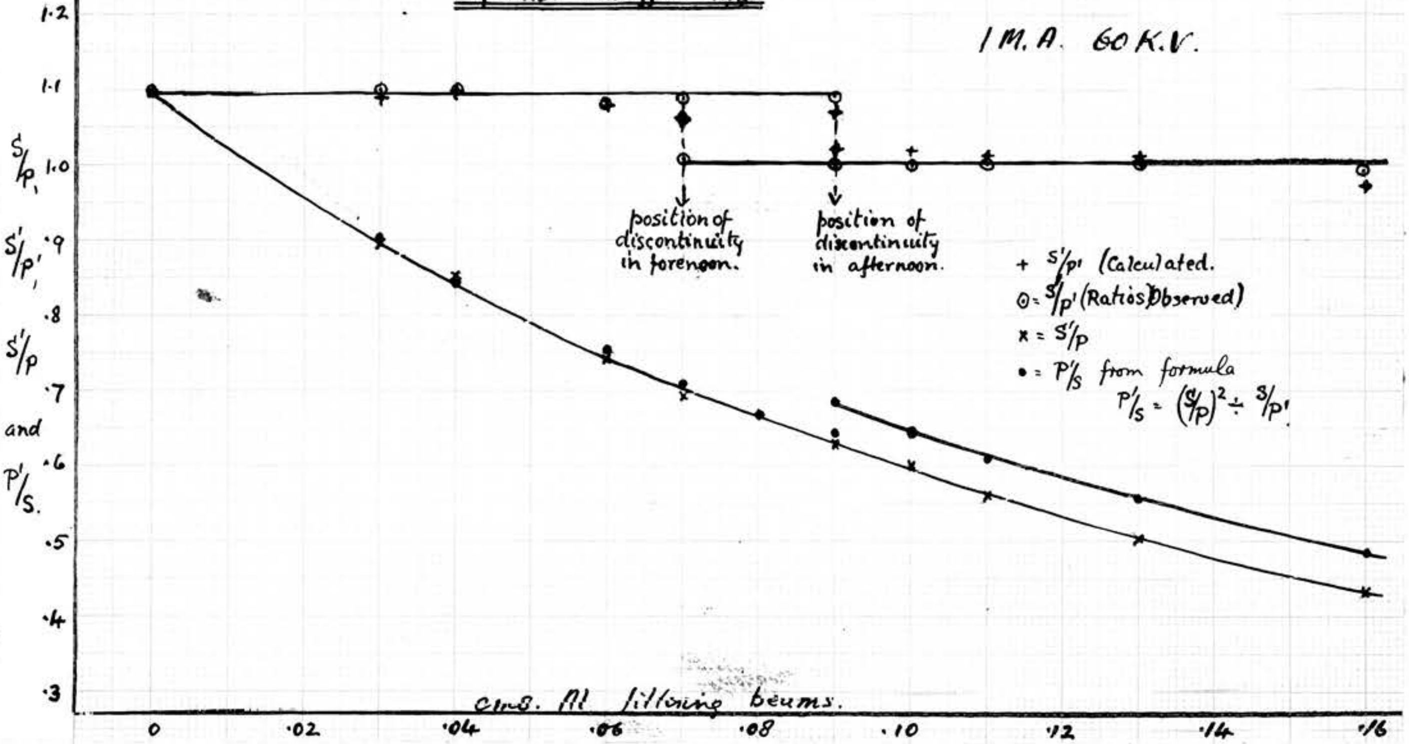


The table of observed and calculated values shows this constancy of ratio.

cms. Al filters.	0	·01	·02	·03	·04	·05	·06
Observed S'/P'	1·42	1·40	1·39	1·39	1·39	1·40	1·39
Calculated S'/P'	1·42	1·42	1·41	1·42	1·44 (?)	1·41	1·40
Ratio $\frac{\text{Observed}}{\text{Calculated}}$	1·00	·985	·985	·98	·97 ?	·99	·99
Observed S/P'	1·42	1·60	1·73	1·88	2·09	2·20	2·42
Calculated P'/S	1·42	1·26	1·17	1·07	·965 ?	·90	·83
Observed S'/P	1·42	1·26	1·16	1·07	·99	·91	·82.

Many other such results were obtained, those in which discontinuities were observed being much more interesting. The curve below was obtained when the MÜLLER Tube was raised and the scatterer was Paraffin Wax, 19 mms. thick, with aluminium foil on its faces. This scatterer was used some fifteen times, giving similar results each time.

19mms. Paraffin Wax.



It will be observed from the curve that the calculated values of $s'/_{p'}$ fitted almost exactly on the observed values of $s'/_{p'}$, and that the ratios $s'/_{p}$ and $P'/_{s}$ fell away at exactly the same rate, showing that the two radiations were equally absorbable in aluminium. At the point of discontinuity, the ratios $s'/_{p}$ remained on the continuation of the absorption curve of its earlier values, but the corresponding values of $P'/_{s}$ became slightly greater than they should have been if absorption had taken place.as before. After this discontinuous increase in the ratio $P'/_{s}$, the ratios $P'/_{s}$ and $s'/_{p}$ again decreased at the same rate, although on different levels.

The/

The following table shows the calculated and observed values of the ratios concerned. The point of discontinuity was well defined and was traced and retraced in either direction. It thus appeared that there was a sudden decrease in the amount of absorption of the primary beam by aluminium, although the rate of absorption of the primary and secondary beams was the same, before and after the point of discontinuity.

Cms. Al filters.	0	·03	·04	·06	·07	·09	·10	·11	·13	·16
Observed S'/P'	1·10	1·10	1·10	1·08	$\left.\begin{matrix}1·01\\1·09\end{matrix}\right\}$	$\left.\begin{matrix}1·00\\1·09\end{matrix}\right\}$	1·00	1·00	1·00	·99
Calculated S'/P'	1·10	1·09	1·10	1·08	1·06	$\left.\begin{matrix}1·02\\1·07\end{matrix}\right\}$	1·02	1·01	1·01	·97
Ratio $\frac{\text{Observed}}{\text{Calculated}}$	1·00	1·01	1·00	1·00	1·03 ~~·95~~	1·02 ·98 ~~·93~~	·98	·99	·99	1·02.
Observed S/P'	1·10	1·33	1·43	1·60	1·69	$\left.\begin{matrix}1·86\\1·78\end{matrix}\right\}$	1·87	1·98	2·16	2·48
Calculated P'/S	1·10	·91	·845	·755	·715	$\left.\begin{matrix}·645\\·68\end{matrix}\right\}$	·645	·61	·56	·485
Observed S'/P	1·10	·90	·85	·74	·69	·63	·60	·56	·50	·43.

In some of these experiments, discontinuities of this type were observed in S'/P and P'/S, both, at the point of discontinuity of the filtering curve, and occasionally at a point where no discontinuity was observed in the filtering curve. In the first of these cases, it was observed that the increase in P'/S was greater than the corresponding increase/

increase in $^{s'}/_{p}$, so that the calculated $^{s'}/_{p'}$ again agreed with the observed value of that ratio. In the second case, the increase in $^{p'}/_{s}$ was exactly the same as the corresponding increase in $^{s'}/_{p}$, so that no change was observed in the calculated ratio $^{s'}/_{p'}$. An increase in the absorption of either of the beams has never been recorded in these experiments. The discontinuity has always been due to a sudden decrease in the absorption of the primary beam; a similar decrease in the absorption of the secondary has also been observed but was always much smaller.

SUMMARY.

The radiation scattered by a material through an angle of 90° to the direction of the radiation incident on the material has been compared, in some four hundred experiments, with the radiation transmitted directly through the material. The materials used in these comparisons were filter paper, paraffin-wax and carbon. Various thicknesses of these substances were used and the hardness of the radiation incident on them was varied during the period of the research. The incident radiation was obtained, in the earlier part of the research, from a COOLIDGE Tube with Molybdenum target, and, in the later part, from a MÜLLER Tube with Tungsten target.

In these comparisons, the author sought to determine whether the scattered radiation was of the same absorbability as the transmitted, or, whether it was more absorbable than the primary. The method used was the ionisation method of comparison of X-radiations. The experimental tests made can be divided up into the following groups:-

GROUP I /

<u>GROUP I</u>:- Experiments on the variation of the ratios $^{s}/_{p}$ and $^{s'}/_{p'}$ with average hardness of the heterogeneous X-radiation incident on the scattering material. Fifty experiments of this type were made and the observations made were:-

(a) Observation of the value of the ratio $^{s}/_{p}$ for the unintercepted transmitted and scattered radiations for different hardnesses of incident radiation.

(b) Observation of the value of the ratio $^{s'}/p'$, when the transmitted and scattered radiations were passed through (constant) equal thicknesses of aluminium and the incident radiation was hardened.

(c) Observation of the value of the ratio $^{s'}/_{p}$ as in (b) except that tin absorbers were substituted for the aluminium absorbers, thus introducing characteristic radiations into the beams entering the electroscopes.

The observations (a) showed the value of $^{s}/_{p}$ to be constant over definite ranges of hardness of the incident radiation, although it was not constant, except in a few cases, throughout the whole range of the hardnesses used in the experiment. The change in value of the ratio occurred discontinuously, thus. As the incident radiation was hardened, the ratio $^{s}/_{p}$ remained constant in value till a certain definite average hardness was reached when its value decreased/

decreased by some 8% and thereafter remained constant at the new value till some other definite average hardness was reached when the discontinuous change was again observed. The average hardnesses at which changes occurred were measured in terms of an average mass-absorption coefficient in aluminium and agree with those observed by previous researchers on this subject. It was also observed that, if the ratio $^{s}/_{p}$ was continuous in value over the range of hardnesses used in the experiment the value remained constant over the range till an average hardness given by $(\frac{\mu}{\rho})_{Al}$ = 1.50 was reached, after which the value of the ratio began to fall slowly.

Observations (b) could be said to behave in the same way as those of (a). The value of $^{s'}/_{p'}$ for a given hardness of incident radiation was less than the corresponding value of the ratio $^{s}/_{p}$. It remained constant in value over given ranges of hardness of the incident radiation, changing discontinuously from one value to another, the change being about 8% and occurring at definite hardnesses of the incident radiation. The discontinuity in $^{s}/_{p}$ was not always accompanied by a discontinuity in $^{s'}/_{p'}$ and vice versa, but the ratio $^{s'}/_{p'}$ showed more tendency to constancy than the ratio $^{s}/_{p}$, this being possibly due to the fact/

fact that the ionising beams entering the electroscope in the former case were more nearly similar and homogeneous. The constancy of $^{s'}/_{p'}$ was especially marked when the absorbing aluminium in each beam was thick.

Observation (c) showed a different tendency. The value of $^{s'}/_{p'}$ with tin absorbers remained constant in value till in the region of hardness given by $(\frac{\mu}{\rho})_{Al}$ = 3.0 to 2.0 the value began to rise quickly and then fall quickly the value varying continuously throughout the change. This was due to the introduction of the tin characteristic radiation in the two beams at different hardnesses of the incident radiation.

<u>GROUP II</u>:- Filtering experiments in which the ratio $^{s'}/_{p'}$ was observed for varying equal thicknesses of absorbing aluminium placed in the transmitted and scattered beams, the incident radiation being kept constant in quality and intensity (as far as possible). Three hundred such experiments were made and gave results which can be best considered in sections.

Fifty/

Fifty to sixty experiments were made with different scatterers and the majority showed the ratio $^{s'}/_{p'}$ to remain constant in value for a range of thickness of the absorbing aluminium in each beam. At a definite hardness of the transmitted beam entering the electroscope, the value decreased by some 8% and thereafter the value again remained constant until another hardness was reached when a further fall of 8% occurred in the value of the ratio $^{s'}/_{p'}$. Some of the experiments showed the value of the ratio $^{s'}/_{p'}$ to decrease continuously with increasing thickness of absorbing aluminium in the beams: this being as required by the COMPTON increase of wave-length theory. Due to results in certain of the above experiments, some two hundred experiments were made to test the appearance of the J-discontinuities on continued exposure of the scatterer to radiation. It had been observed that the continuous decrease in $^{s'}/_{p'}$ with increasing thickness of absorber had been obtained initially in a number of experiments but that, if the scatterer had been exposed to radiation previous to the experiment, the J-discontinuities appeared. The experiments sought to show that the appearance of the discontinuities was due to exposure of the scatterer and to this end changes were made in/

in the absorbing sheets, in the scatterer and in the method of exposure. The list of experiments made has been appended to this thesis and can be consulted ~~[illegible]~~ but a short summary will be given here. The scatterers used were various thicknesses of paper, paraffin-wax and carbon.

Number of experiments made	196
Change observed in - - -	160
No change observed in - -	36
Development from slope to discontinuities observed in	84
Development from discontinuities to slope observed in	32
Probable development from slope to discontinuities in	9
Irregularities developed in	6
Development to discontinuities and return to slope in -	23
New scatterer introduced in	20
Curve from initial exposure of new scatterer - slope in	18
Curve from initial exposure of new scatterer - discontinuous in - - - - -	2

The experimental results showed that the previous exposure of the scattering material had an effect on the results, the J-discontinuities appearing on exposure. Included in the thirty-two cases in/

in which no development was observed are experiments in which the scatterer was given a long exposure to radiation before the filtering experiment was repeated and thus possibly had passed through the stage at which discontinuities would have been obtained and had again reached the state in which the continuous decrease in $^{s'}/_{p'}$ was observed. The two cases in which discontinuities were observed on inserting a fresh scatterer occurred in experiments in which the initial curve of the first scatterer had been discontinuous.

Thus, of the two types of change,

(a) From slope to discontinuity.

(b) From discontinuity to slope.

type (a) occurs more frequently than type (b), except, it may be noted, in the case of carbon scatterers. When the change did occur, insertion of a fresh scatterer of the same dimensions and material, produced the results obtained in the first exposure of the original scatterer. If the scatterer was left in position and exposed to the radiation for some time, it was found that the change, when it did occur, took place whether the electroscopes were shielded by lead or not. Thus it is most probable that the change is due to exposure and to exposure only. It is also almost/

almost certain that /exposure of/ the scatterer is the cause.

Results of experiments on charged and uncharged paraffin wax scatterers showed no difference to have been produced. A thin paraffin wax scatterer (11 mms.) gave a change from discontinuities to slope when inserted in place of a thick paraffin wax scatterer (19 mms.) which had previously shown the discontinuities. Re-insertion of the thick scatterer again showed the discontinuities to be present. The thick scatterer was faced with Aluminium foil .001 cm. thick, while the thin one was of paraffin wax solely.

A series of thirty experiments on the filtering of the primary and secondary beams after scattering from 19 mms. paraffin wax showed discontinuities to be present:-

either (a) In the primary alone.

or (b) In both primary and secondary at the same point.

It was observed that the values of s'/p', for a given thickness of Aluminium in each beam, as calculated from the observed ratios s/p, s/p' and s'/p, agreed with those measured by experiment, the discontinuity occurring at the same point in both. It was also observed that the ratios s'/p and p'/s fell away at the same/

same rate till the discontinuity was reached; at this point, there were two possibilities corresponding to cases (a) and (b) above.

In case (a), it was observed that there was a sudden decrease in the absorption of the primary, no change being noted in the absorption of the secondary.

In case (b), both primary and secondary absorptions decreased slightly, i.e. became less than their values should have been if they had been absorbed at the same rate throughout. If a discontinuity was observed in the ratio s'/p', the primary decrease was greater than the secondary, so that there was a fall in the ratio s'/p'. In this type of result, changes were occasionally observed in both beams at the same point, while no change was apparent in s'/p' observed and calculated. This was due to the corresponding changes cancelling one another.

In these experiments, if a slope was obtained, as the filtering curve, the values of p'/s and s'/p decreased steadily and showed the primary more absorbable than the secondary.

The superposition of characteristic radiation

(a) on the main primary and secondary beams by adding some silver to the scatterer,

(b) on the beams inside the electroscopes by adding gold-leaf to the back wall of these,

did/

did not affect the result obtained, or rather did not prevent the appearance of discontinuities, although in case (b) the results were rather erratic at times. The presence of the characteristic radiation in case (a) was very evident in the rise in ratio, although some of the rise was due to absorption of the primary beam in passing through the silver.

C O N C L U S I O N/

CONCLUSION

Experiments on the variation of $^s/_p$ and $^{s'}/_{p'}$ with average hardness of the radiation incident on the scatterer show that the scattered radiation is sometimes more absorbable than the primary, since the value of $^s/_p$ for the unintercepted radiations is greater than the value of $^{s'}/_{p'}$ observed when the transmitted and scattered radiations are passed through absorbing sheets of aluminium, and since there is a rise and fall in the value of $^{s'}/_{p'}$ when tin absorbers are used, the rise and fall can be explained only on the supposition that the scattered radiation is less penetrating than the transmitted. The values of $^s/_p$ and $^{s'}/_{p'}$ do not vary with increasing penetrating power of the incident radiation as should be expected on the COMPTON change of wave-length theory.

The number of filtering experiments made during the research and the results obtained in them allow the following conclusions to be reached:-

I. The value of $^{s'}/_{p'}$ does not always decrease continuously with increase in the thickness of Aluminium filtering the transmitted and scattered radiations. Discontinuities may occur in the values of $^{s'}/_{p'}$/

$^{s'}/_{p'}$; these discontinuities, when they occur, separate the observations into sections in each of which the value of $^{s'}/_{p'}$ is a constant. At the point of discontinuity, the value of $^{s'}/_{p'}$ decreases by some 8% and the value of $^{s'}/_{p'}$ again remains constant over another range of increasing thickness of aluminium filters. These discontinuities occur when the average hardness of the transmitted radiation is given by $(\frac{\mu}{\rho})_{Al}$ = 4.0, 3.4, 3.0, 2.4, 1.7 and 1.3. approximately.

II. There can be traced a change from the continuous variation of the ratio $^{s}/_{p'}$ with thickness of absorbing Aluminium, to that type of variation which characterises the J-phenomenon. These changes have also been observed in the reverse order.

III. The change in II. above seems to be due to continued exposure of the scatterer to X-radiation.

IV. Charging the scatterer does not alter the type of result, at least when the discontinuities are evident.

V./

V. When discontinuities occur, the transmitted and secondary radiations are equally absorbable till the point of discontinuity is reached when the absorbability of the primary decreases slightly and the two beams become equally absorbable but at this different "level".

VI. Superposition of a characteristic radiation on the primary and secondary beams does not prevent the appearance of the discontinuous curve.

Conclusion I is evident from the figures given above and from previous papers on this subject by other investigators: II and III are due to experiments dealt with at some length using a scatterer of 24 sheets of filter-paper: IV has been tested for high and low voltages, given respectively by a WIMSHURST and dry batteries: V has been dealt with in a number of experimental tests and tables given of the results of calculations; and VI has been shown to be true if silver be added to the scatterer and if gold-leaf be attached to the back wall of the electroscopes, although this latter method is not very/

very satisfactory.

Thus it may be concluded from these researches, that there seems to be a change from one type of result to the other, the change being due to exposure of the scatterer. The reason for this change is not yet known although its cause was sought for in a number of directions. Ionisation in the scatterer was thought to be the cause or a cause, but artificial charging of the scatterer by other means did not change the type of result ~~experimented on~~, although only discontinuous curves were dealt with. The cause of the discontinuities remains unknown, although it seems to be due to a decrease in the absorption of the rays by the Aluminium filters at the critical hardnesses usually measured in this work. This decrease in absorption seems to occur in the primary rather than in the secondary beam. Scatterers of carbon, paper, paraffin wax, aluminium and plywood were used and all except plywood showed discontinuities. All the other scattering materials showed either the change from the slope to discontinuities or the reverse effect. Discontinuities were observed very regularly with a scatterer of paraffin wax, 19 mms. thick, a result quite remarkable and unexpected, on account of the thickness of the/

the scatterer, as variation due to small irregularities in the scatterer, which might cause unexpected effects, must surely be regarded as balancing out, with such thicknesses of scattering material. Thick scatterers give more stable and persistent results than thin scatterers, possibly due to the absorption in the scatterer making the transmitted and scattered radiations almost equally absorbable.

A P P E N D I X.

giving

TABLES OF RESULTS OF EXPERIMENTS

on

THE EFFECT OF EXPOSURE

of

THE SCATTERER.

and

ADDITIONAL CURVES ON MATTERS

TREATED IN THE PAPER.

RESULTS OF EXPERIMENTS

DATE	SCATTERER	INITIAL CURVE	TYPE OF EXPT.	DEVELOPMENT	DEVELOPMENT BACK
17.2.29	24 sh. Paper	slope	Expt. aft. expt.	none	-
27.2.29	" " "	"	" " "	to discs.	none
27.2.29	" " "	"	" " "	to discs.	apparently
28.2.29	" " "	"	" " "	to discs.	none
2.3.29	12 " "	"	Expos. bef.rept.	none	-
5.3.29	12 " "	"	" " "	none	-
5.3.29	24 " "	"	Expt. aft. expt.	none	-
4.3.29	24 " "	"	" " "	none	-
6.3.29	18 " "	"	" " "	none	-
66.3.29*	24 " "	"	" " "	none	-
7.3.29*	24 " "	"	" " "	none	-
20.3.29	36 " "	"	" " "	to dis cs.	-
21.3.29	36 " "	"	" " "	to discs.	-
21.3.29	36 " "	"	" " "	to discs.	-
22.3.29	36 " "	"	" " "	doubtful	-
17.4.29	24 " "	"	" " "	to discs.	-
17.4.29*	24 " "	partial slope	" " "	to dis cs.	on standing
18.4.29	36 " "	slope	" " "	none	-
18.4.29	24 " "	"	Expos. bef. expt.	smaller slope	-
19.4.29	24 " "	"	Expt. aft. expt.	doubtful	on exposure
19.4.29	24 " "	"	" " "	none	-
20.4.29	24 " "	"	" " "	none	-
24.4.29	24 " "	"	" " "	Discs. aft. exposure	-
24.4.29	24 " "	"	Expos. bef. expt.	Discs.	-
25.4.29	24 " "	"	" " "	Discs.	-

* *In experiments marked thus, the scatterer had been exposed to X-radiation before observations were made.*

ON EXPOSURE EFFECT
If doubtful.

PROB. DEVELOPMENT	IMPROBABLE DEVELOPMENT.	NEW SCATTERER INTRODUCED.	APERTURES
-	-	-	4 pinholes $1\frac{1}{2}$" hole
-	-	slope	as above.
-	-	slope	as above
-	-	-	as above
-	-	-	3 pinholes $1\frac{3}{4}$" hole
-	-	-	3 pinholes $1\frac{3}{4}$" hole
-	-	Exposed Scatterer Discs.	4 pinholes $1\frac{1}{2}$" hole
-	-	Exposed. Discs.	as above
-	-	Exposed Slope	as above
-	-	-	as above
-	-	-	as above
-	-	-	5 pinholes $1\frac{1}{4}$" hole
-	-	Exposed Slope	as above
-	-	Unsatisfactory	as above
yes	-	-	as above
-	-	slope	4 pinholes $1\frac{1}{2}$" hole
-	-	-	as above
-	-	-	as above
-	-	-	as above
yes	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	slope	as above
-	-	-	as above

DATE	SCATTERER	INITIAL CURVE	TYPE OF EXPT.	DEVELOPMENT	DEVELOPMENT BACK.
25.4.29	24 sh. Paper	slope	Expos. bef. Expt.	to discs.	-
25.4.29	24 " "	slope	" " "	to discs	-
27.4.29	24 " "	slope	" " "	none	-
29.4.29	24 " "	"	" " "	doubtful	-
1.5.29	24 " "	"	expt. aft. expt.	to discs.	after expos.
1.5.29	24 " "	"	expos. bef. expt.	none	-
2.5.29	24 " "	disc.	expt. aft. expt.	to slope	-
2.5.29	24 " "	slope	" " "	discs.	-
3.5.29	24 " "	slope	expos. bef. expt.	doubtful	-
4.5.29	24 " "	"	" " "	discs.	-
8.5.29	24 " "	"	" " "	none	-
8.5.29	24 " "	"	" " "	none	-
9.5.29	24 " "	"	" " "	to discs.	-
10.5.29	24 " "	"	" " "	to discs	-
11.5.29	24 " "	"	" " "	to discs	-
13.5.29	24 " "	"	" " "	to discs.	-
16.5.29	24 " "	"	" " "	none	-
16.5.29	24 " "	"	" " "	none	-
17.5.29	24 " "	"	" " "	to discs.	-
22.5.29	24 " "	"	" " "	to discs .	-
22.5.29*	24 " "	Disc.	allowed to stand	slope	-
23.5.29	24 " "	slope	expos. bef. expt.	to discs.	to slope aft. expos.
24.5.29	24 " "	slope	" " "	none	-
29.5.29	24 " "	slope	" " "	to discs.	after expos.
31.5.29	24 " "	"	expt. aft. expt.	to two levels	-
3.6.29	24 " "	"	" " "	none	-
3.6.29	24 " "	"	" " "	to discs	to slope

If Doubtful

PROB. DEVELOPMENT	IMPROBABLE DEVELOPMENT.	NEW SCATTERER INTRODUCED.	APERTURES
-	-	slope	4 pinholes $1\frac{1}{2}$" hole
-	-	-	as above
-	-	-	as above
yes	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	slope	as above
-	-	-	as above
yes	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above $1\frac{3}{4}$" hole
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	slope	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	as above
-	-	-	5 pinholes as above
-	-	-	as above
-	-	-	as above

DATE	SCATTERER	INITIAL CURVE	TYPE OF EXPT.	DEVELOPMENT	DEVELOPMENT BACK.
4.6.29	24 sh. Paper	slope	repetition	discs.	-
25.6.29	24 " "	slope	"	irregular	-
25.6.29	24 " "	discs.	"	slope	*
26.6.29	24 " "	irregular	"	slope	-
26.6.29	24 " "	irreg.discs	"	"	-
27.6.29	plywood	slope	"	irregular	-
27.6.29	aluminium	discs.	"	discs.	-
28.6.29	9mm. P.W.	discs.	"	slope	-
29.6.29	24 sh. Paper	slope	"	none	-
1.7.29	plywood	slope	"	none	-
5.7.29	24 sh. Paper	slope	"	none	-
8.7.29	24 sh. Paper	broken slope	"	discs.	-
8.7.29	24 " "	" "	"	slope	-
9.7.29	24 " "	slope	"	none	-
11.7.29	24 " "	"	"	discs.	on exposure
12.9.29	24 " "	discs.	"	slope	-
18.9.29	24 " "	broken slope	"	slope	-
18.9.29	24 " "	slope	"	none	-
19.9.29	24 " "	discs	"	slope	discs. on expos
19.9.29	24 " "	slope	"	discs	-
20.9.29	24 " "	"	"	none	-
20.9.29	24 " "	discs.	"	slope	-
23.9.29	24 " "	slope	"	discs.	-
23.9.29	24 " "	slope	"	discs	slope on expos.
24.9.29	24 " "	slope	"	discs.	slope on expos.
25.9.29	24 " "	prob. discs	"	slope	-
26.9.29	24 " "	slope	"	none	-

If Doubtful

PROB. DEVELOPMENT	IMPROBABLE DEVELOPMENT	NEW SCATTERER	APERTURES
-	-	slope	4 pinholes 1¼"
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		14 pinholes 2¼"
-	-		4 pinholes 5 holes 6½ mms
-	-		4 pinholes 1¼"
-	-		" 29 holes .7 cm
-	-		4 pinholes 1¼"
-	-		" "
-	-		" "
-	-		" "
-	-		3 pinholes "
-	-		" "
-	-		5 pinholes "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "

DATE	SCATTERER	INITIAL CURVE.	TYPE OF EXPT.	DEVELOPMENT	DEVELOPMENT BACK
26. 9.29	24 sh. Paper	discs.	repetition	slope	-
27. 9.29	24 " "	slope	"	discs.	on expos.
30. 9.29	24 " "	slope	"	discs.	probable
1.10.29	24 " "	slope	"	broken slope	slope
2.10.29	24 " "	slope irreg.	"	slope	-
2.10.29	24 " "	slope	"	none	-
3.10.29	24 " "	slope	"	discs.	slope
4.10.29	24 " "	slope	"	discs.	-
11.10.29	24 " "	slope	"	discs.	-
15.10.29	24 " "	slope	"	discs.	-
15.10.29	24 " "	slope & disc.	"	slope	-
18.10.29	24 " "	slope	"	discs.	-
23.10.29	24 " "	discs.	"	slope	-
24.10.29	24 " "	discs.	"	slope	-
25.10.29	24 " "	slope	"	discs.	-
26.10.29	24 " "	discs.	"	slope	-
30.10.29	24 " "	slope	"	discs.	slope on expos.
2.11.29	24 " "	slope	"	none	-
25.11.29	24 " "	slope	"	discs.	slope on expos
27.11.29	24 " "	slope (broken)	"	discs.	-
28.11.29	24 " "	slope	"	none	-
29.11.29	24 " "	slope	"	doubtful	-
2.12.29	24 " "	slope	"	none	-
- 4.12.29	24 " "	slope	"	discs.	-
4.12.29	24 " "	slope	"	discs.	slope on expos.
5.12.29	24 " "	slope	"	discs.	-
9.12.29	9 cms. P.W.	slope	"	discs.	appt. on exp.
10.12.29	9 " "	slope	"	discs	-
10.12.29	11 " "	slope	"	discs.	-

If doubtful

PROB. DEVELOPMENT	IMPROBABLE DEVELOPMENT	NEW SCATTERER	APERTURES
-	-		5 pinholes $1\frac{1}{4}$"
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-	slope	" "
-	-	discs.	" "
-	-	slope	" "
-	-	slope	" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
-	-		" "
yes	-		" "
-	-	-	" "
-	-		" "
-	-		" "
-	-	slope	" "
-	-		" 5 1cm. holes
-	-		" "
-	-		" "

DATE	SCATTERER	INITIAL CURVE	TYPE OF EXPT.	DEVELOPMENT	DEVELOPMENT BACK
11.12.29	11 mm. P.W.	slope (broken)	repetition	discs.	-
11.12.29	9 mm. P.W.	"	"	discs.	-
12.12.29	9 mm. P.W.	irreg. slope	"	none	-
12.12.29	11 mm. P.W.	slope	"	broken slope	-
13.12.29	11 mm. P.W.	slope	"	discs.	-
13.12.29	24 sh. Paper.	slope	"	discs.	-
17.12.29	24 " "	"	"	none	-
8. 1.30	24 " "	discs.	-	-	-
13. 1.30	24 " "	slope		probable	-
13. 1.30	24 " "	slope	"	discs	-
14. 1.30.	24 " "	broken slope	"	discs.	-
15. 1.30.	6 mm. Carbon	discs.	"	slope	-
16. 1.30	6 mm. Carbon	"	"	slope	-
29. 1.30	24 sh. Paper	discs.	"	broken slope	-
31. 1.30	12 mm. Carbon	discs.	"	none	-
1. 2.30	12 " "	"	"	none	-
3. 2.30	12 " C.	slope	"	discs	-
5. 2.30	12 " C.	slope	"	discs	-
5. 2.30	12 " C.	slope	"	"	-
21. 2.30	9 " C.	discs.	"	slope	*
11. 3.30	70 sh. Paper	slope	"	discs.	-
24. 3.30	24 sh. "	broken slope	"	discs.	-
25. 3.30	24 " "	slope	"	discs.	slowly
25. 4.30	70 " "	slope	"	discs.	-
7. 5.30	24 " "	slope (broken)	"	discs.	-
7. 5.30	24 " "	slope (broken)	"	discs.	-

If doubtful.

PROB. DEVELOPMENT	IMPROBABLE DEVELOPMENT	NEW SCATTERER	APERTURES
-	-	slope	5 pinholes 5 1cm. holes
-	-		as above.
-	-		6 pinholes as above.
-	-		as above.
-	-		as above.
-	-		5 pinholes 1 3/8 in. diam.
-	-		as above
-	-		as above
yes	-		as above
-	-		as above
-	-		as above
-	-	discs.	6 pinholes as above
-	-		as above 1 in. diam.
-	-		5 pinholes as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		6 pinholes 1 1/4 in. diam
-	-		5 pinholes 1 1/2 in. diam.
-	-		as above
-	-	slope	4 pinholes as above
-	-		as above

DATE	SCATTERER	INITIAL RESULT	TYPE OF EXPT.	DEVELOPMENT	DEVELOPMENT BACK
8.5.30	24 sh. Paper	slope	Repetition	discs	-
10.5.30	24 " "	slope	"	discs	-
14.5.30	24 " "	slope	"	discs.	to slope
14.5.30	24 " "	slope	"	discs.	-
20.5.30	12 " "	slope	"	less steep slope	-
20.5.30	18 " "	slope	"	discs.	-
20.5.30	18 " "	slope	"	probable	-
21.5.30	18 " "	slope	"	irregular	-
22.5.30	36 " "	slope	"	discs.	to slope
2.6.30	26 " "	slope (irreg)	"	slope	-
3.6.30	26 " "	slope	"	none	-
4.6.30	26 " "	irreg. slope	"	slope	-
4.7.30	24 " "	discs.	"	slope	-
7.7.30	24 " "	almost discs.	"	slope	-
8.7.30	24 " "	slope	"	discs	-
14.7.30	24 " "	slope	"	discs.	-
18.9.30	24 " "	slope	"	probable	-
26.9.30	24 " "	irreg. slope	"	discs.	-
30.9.30	24 " "	slope	"	discs.	-
1.10.30	24 " "	slope	"	discs.	-
2.10.30	24 " "	broken slope	"	discs.	-
23.10.30	19 mms. P.W.	slope	"	discs.	-
24.10.30	19 " "	broken slope	"	discs.	to slepe
29.10.30	19 " "	slope	"	discs.	-
12.11.30	11 mms. P.W.	discs.	"	slope	-
19.11.30	19 mms. P.W.	discs.	"	slope	-
11.12.30	19 mms. P.W.	broken slope	"	discs.	-
13.1.31	19 mms. P.W.	broken slope	"	discs.	-
14.1.31	19 " "	horizontal	"	slope	-
21.1.31	19 " "	discs.	"	slope	-
21.1.31	19 " "	slope	"	discs.	-
13.10.31	19 " "	horizontal	"	slope	-
23.10.31	19 " "	slope	"	probable	-

If doubtful

PROB. DEVELOPMENT	IMPROBABLE DEVELOPMENT	NEW SCATTERER	APERTURES
-	-	slope	4 pinholes $1\frac{1}{2}$ in. diam
-	-	slope	as above
-	-		as above
-	-		as above
-	-		as above 2 in. diam.
-	-		as above
yes	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
yes	-		as above
-	-		as above
-	-		as above
-	-		as above as above
-	-		as above as above
-	-		5 pinholes $5/8$ in. diam.
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
-	-		as above
yes	-		as above

SYNOPSIS OF RESULTS

SCATTERER.	INITIAL CURVE	NO. OF EXPTS.	NO DEVEL.	DEVELOPMENT to Slope	to Discs
24 sheets Filter Paper.	Irregular	5	0	3	2
	Slope	87	On Rep$^{n.}$ 19 On Exp$^{r.}$ 7	- -	38 13
	Broken Slope	10	0	2	8
	Discs.	15	1	14	0
	TOTAL	117	27	19	71
12 sheets Filter Paper.	Slope	3	2	1 less steep slope	-
18 sheets Filter Paper	Slope	4	1	-	1
26 sheets Filter Paper	Slope	1	1	-	-
	Irregular Slope	2	-	2	-
36 sheets Filter Paper	Slope	6	1	-	4
70 sheets Filter Paper	Slope	2	-	-	2

SYNOPSIS OF EXPERIMENTS

SCATTERER.	INITIAL CURVE	NO. OF EXPTS.	NO DEVEL.	DEVELOPMENT to Slope	DEVELOPMENT to Discs.
9 mms. Paraffin Wax.	Slope	4	1	-	3
	Discs	1	-	1	-
11 mms. Paraffin Wax.	Slope	3	-	1 (broken slope)	2
	Broken Slope	1	-	-	1
	Discs	1	-	1	-
19 mms. Paraffin Wax.	Slope	4	-	-	3
	Broken Slope	3	-	-	3
	Discs	4	-	4	-
Plywood	Slope	2	1	-	-
Aluminium.	Discs	1	-	-	1 (Difft. Type)
<u>6</u> mms. Carbon	Discs	2	-	2	-
9 mms. Carbon	Discs	1	-	1	-
12 mms. Carbon	Slope	3	-	-	3
	Discs	2	2	-	-
TOTALS					
Paper Scatterers, Carbon ", P.W. ", Al. ", Plywood "	Slope	119	33	2 (Difft. Type)	69
	Broken Slope	14	-	2	12
	Irregular	7	-	5	2
	Discs	27	3	23	1 (Difft. Type)

OF EXPERIMENTS.

PROB. DEV. TO DISCS.	BECOMING IRREG.	RETURN TO SLOPE.	RETURN TO DISCS.	NEW SCATTERER	REMARKS
-	-	1	0	none used	
4 2	3 1	18 0	- -	12 (slope)	
0	0	1	-	1 (slope)	
0	0	0	1 (prob)	3 {1 (Disc) 2 (Slope)}	
6	4	20	1 (prob)	16 {15 (slope) 1 (Disc)}	
-	-	-	-	-	
1	1	-	-	1 (slope)	
-	-	-	-	-	
-	-	-	-	-	
1	-	1	-	1 (slope)	
-	-	-	-	-	

(PAGE TWO).

PROB. DEV. to Discs.	BECOMING IRREG.	RETURN to Slope.	RETURN to Discs.	NEW SCATTERER	REMARKS
-	-	1	-	-	
-	-	-	-	-	
-	-	-	-	1 (slope)	
-	-	-	-	-	
-	-	-	-	-	
1	-	-	-	-	
-	-	1	-	-	
-	-	-	-	-	
-	1	-	-	-	
-	-	-	-	-	
-	-	-	-	1 (Discs)	
-	-	-	-	-	
-	-	-	-	-	
-	-	-	-	-	
9	6	20	-	15 (slope)	
-	-	2	-	1 (slope)	
-	-	1	-	-	
-	-	-	1 (prob	4 (2 Discs) (2 Slope)	

C U R V E S

showing

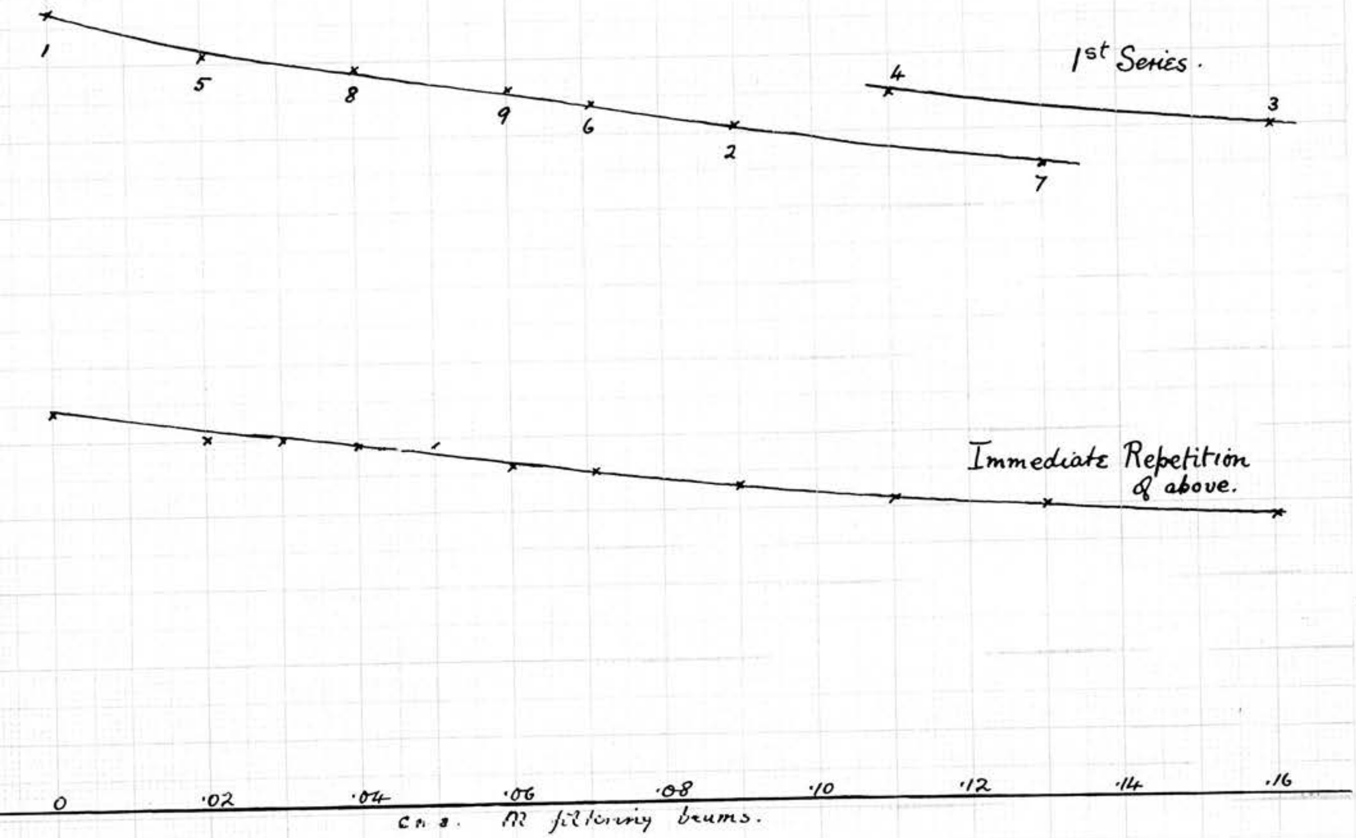
DEVELOPMENT OF THE J-DISCONTINUITIES

WITH

EXPOSURE OF THE SCATTERER.

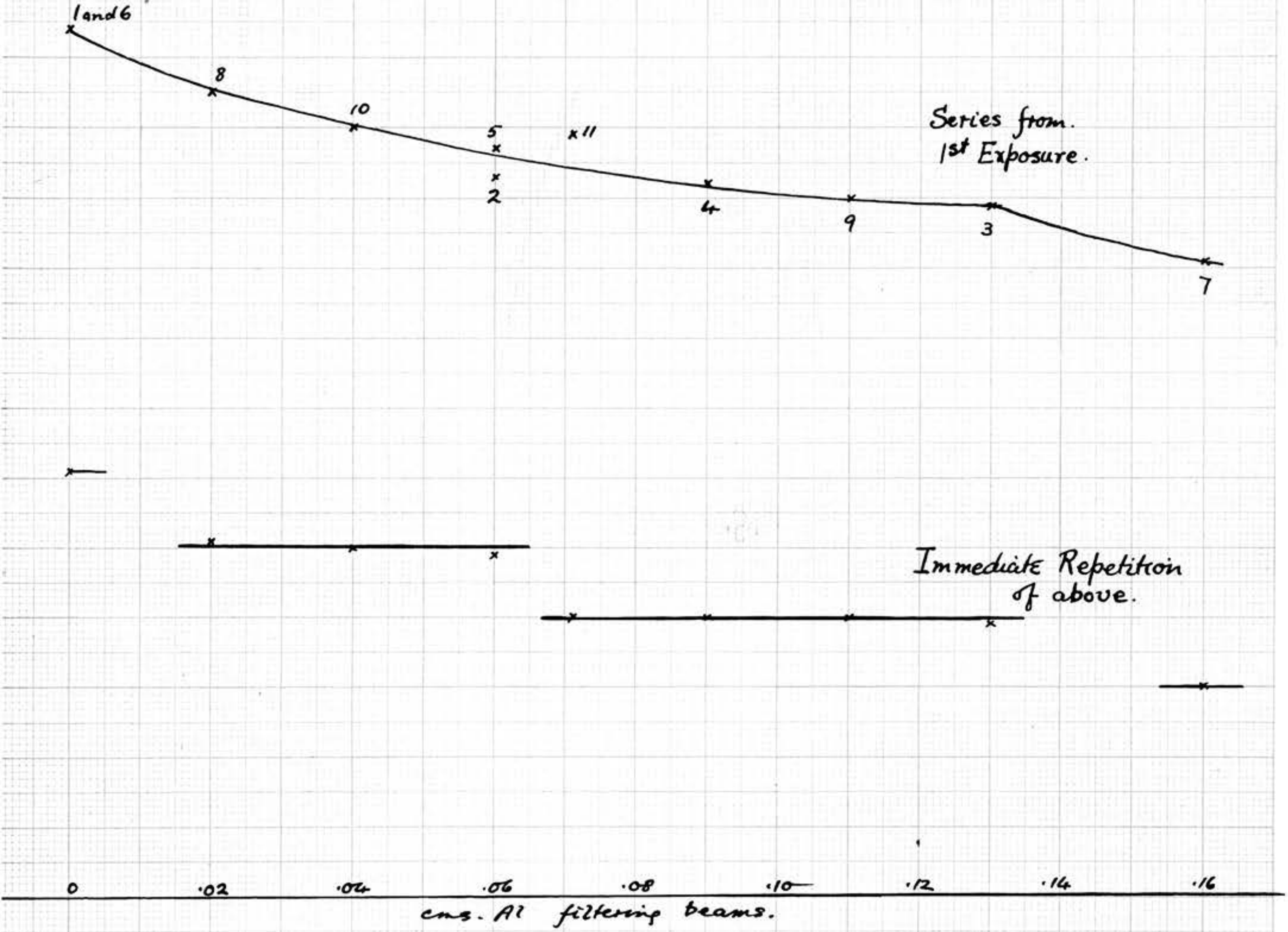
12 sheets Paper

1.8 M.A. 60K.V.



Although repetition gives a smooth slope, the slope is more gradual than that of the first series.

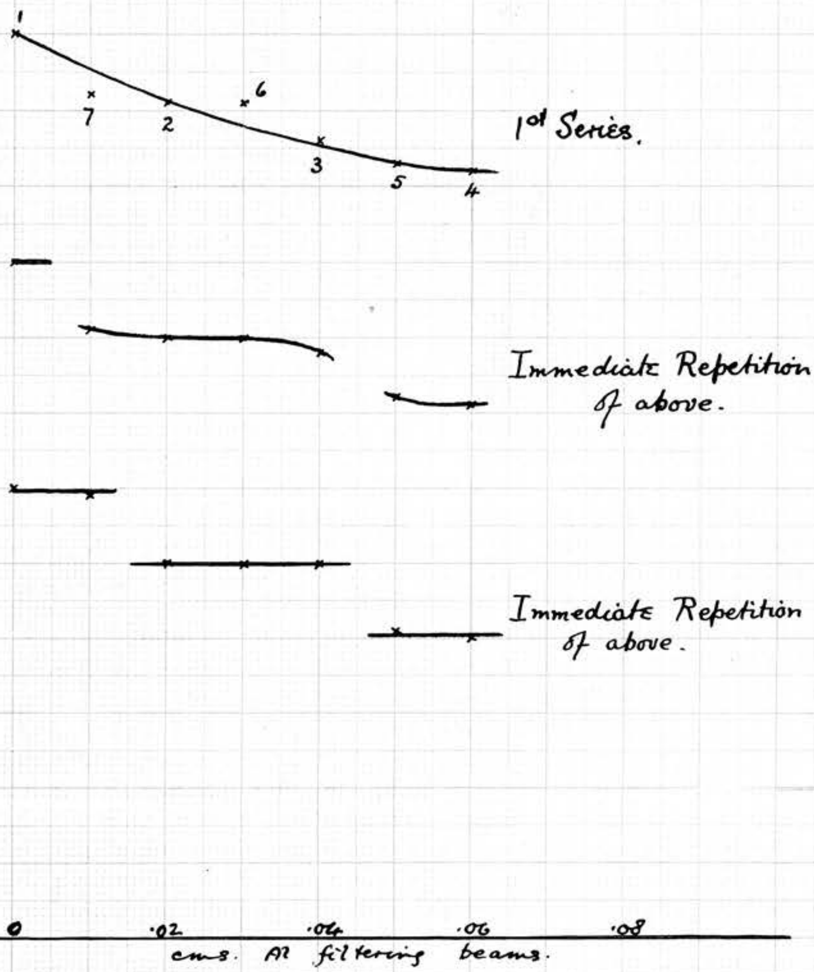
18 sheets Paper.



The first series of observations shows irregularities, especially in the later readings, and the discontinuities are clearly marked on repetition.

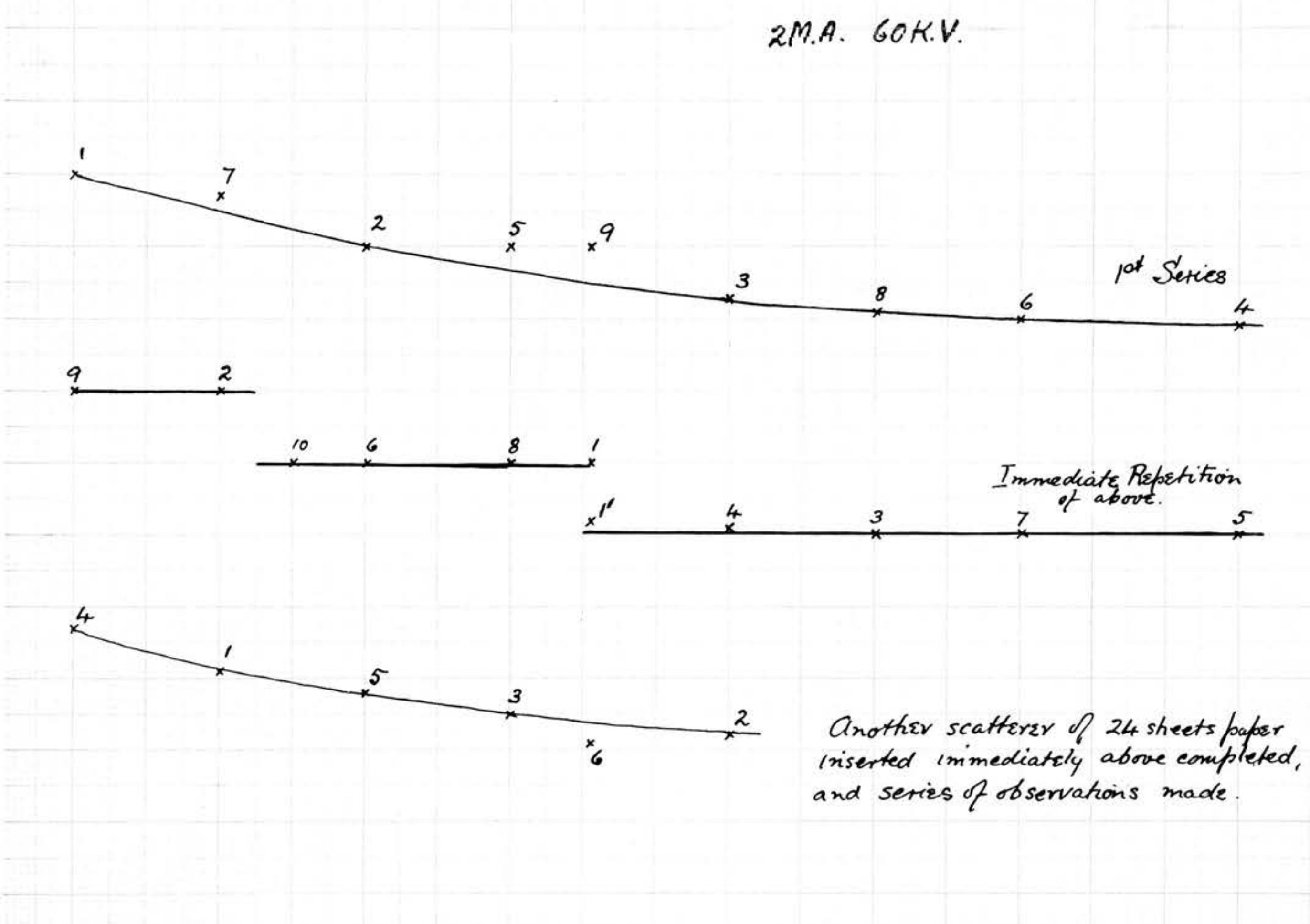
24 sheets Paper

1.6 M.A. 60 K.V.



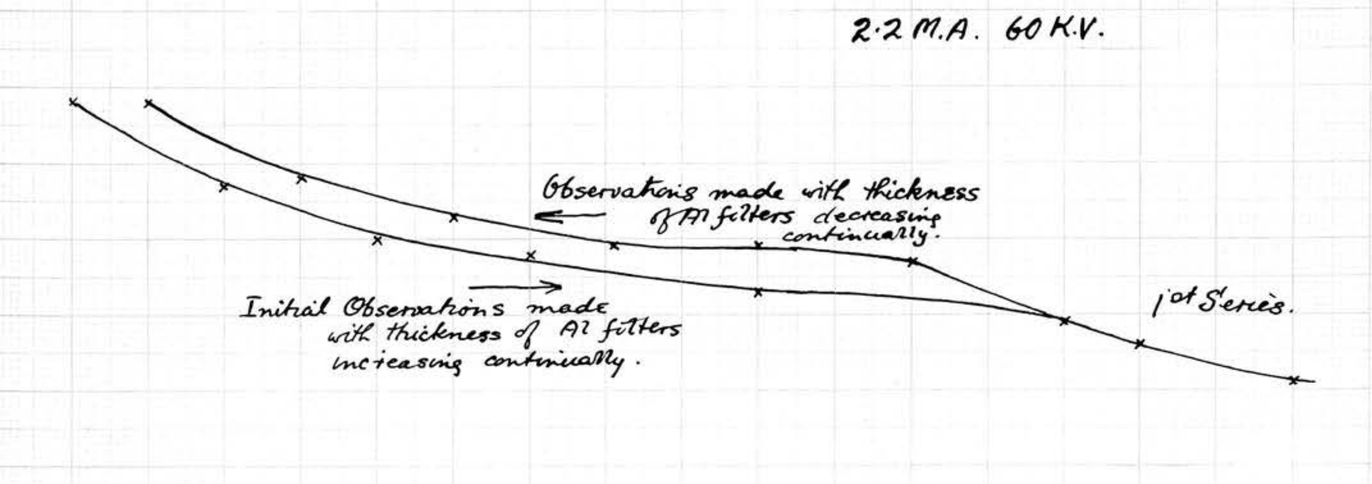
Development from slope to discontinuities is evident. The later observations of the first series seem to indicate the existence or the development of the discontinuities.

24 sheets Paper.



Most of the observations in the first series lie on the smooth slope of the filtering curve, but later observations in the 1st series show that the discontinuities are appearing. A new scatterer, inserted immediately they are evident, gives the smooth slope as the filtering curve.

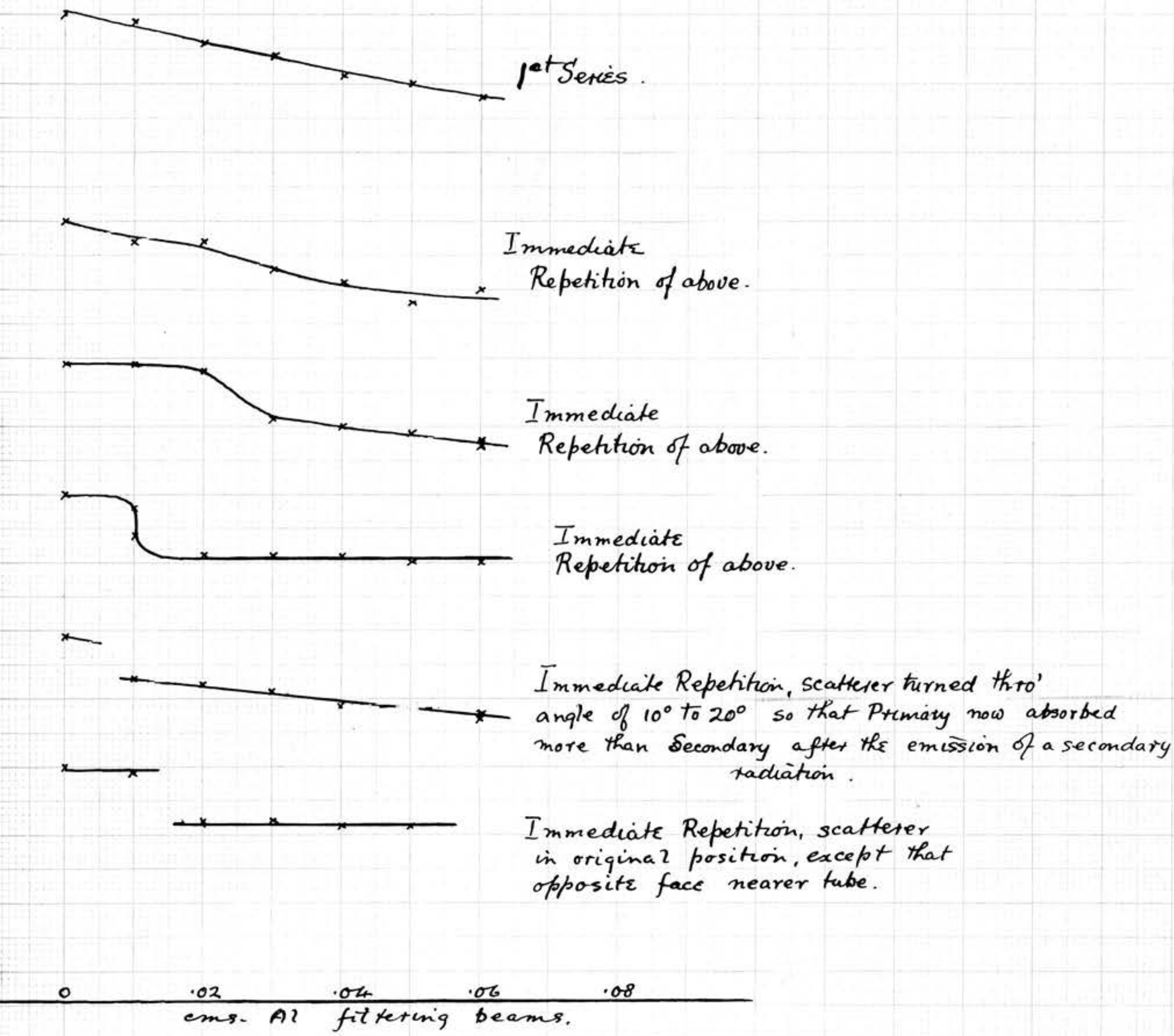
24 sheets Paper.



The first series shows the development of the discontinuities which are evident on repetition.

24 sheets Paper

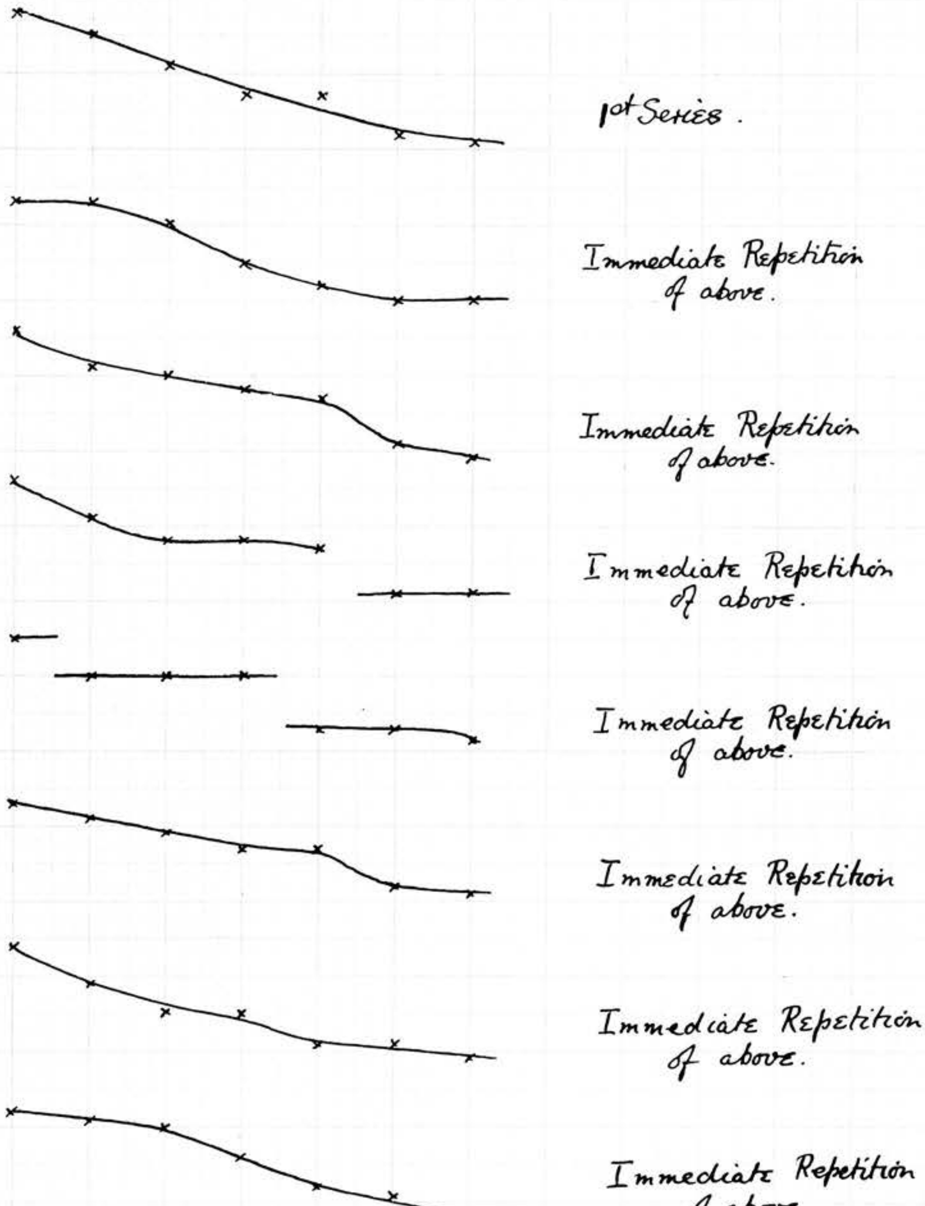
1.43 M.A. 60 KV.



The development from smooth slope to discontinuities takes place, the discontinuities persisting for some time.

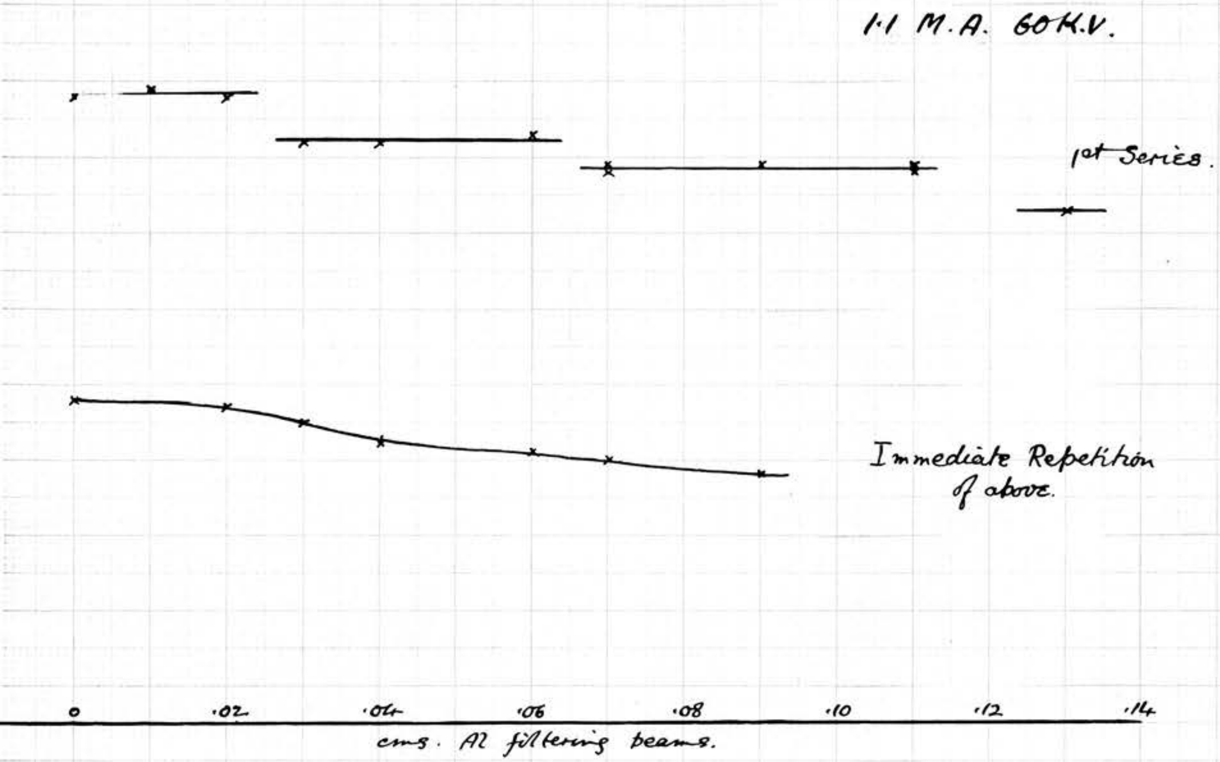
24 sheets Paper.

1·20 M.A. 60K.V.



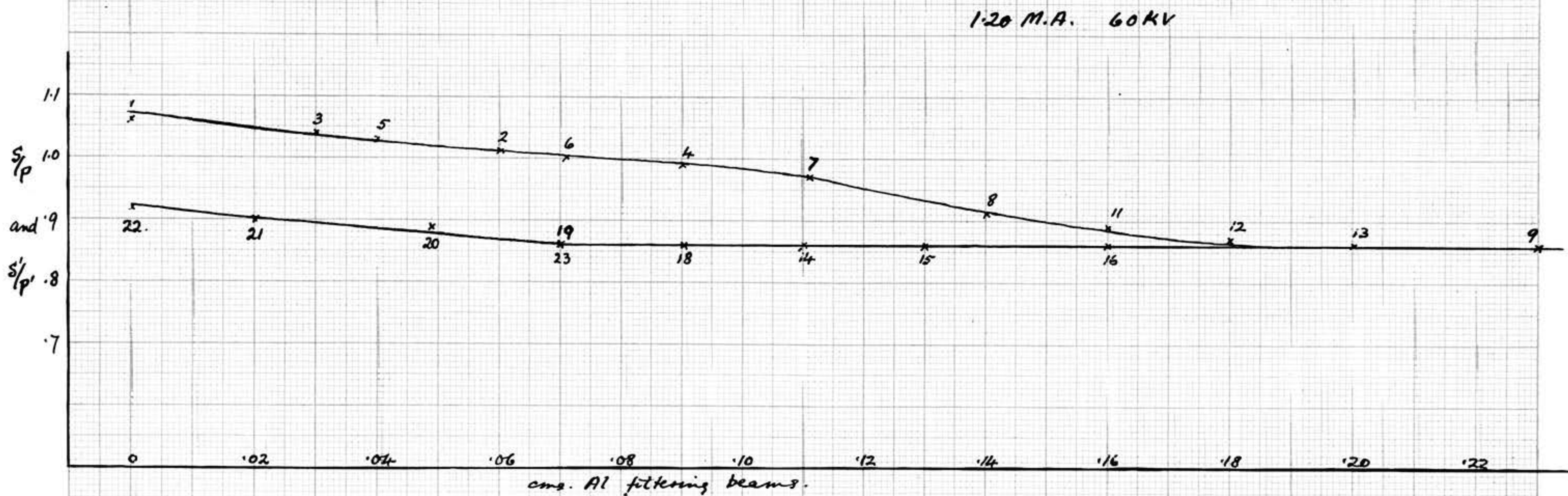
Discontinuities develope and disappear again into an almost smooth slope.

9mms. Carbon.



Discontinuities evident in first series almost disappear on repetition.

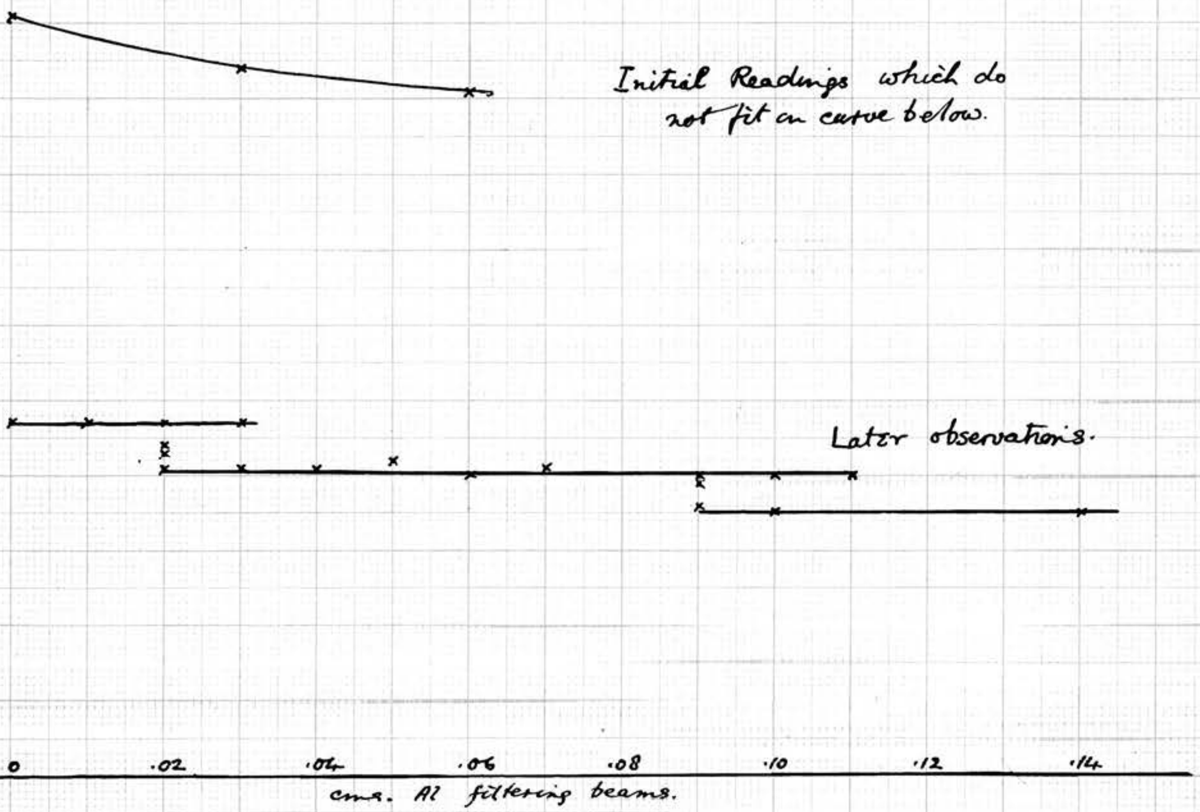
12 mms. Carbon.



The values of the ratios S'/p' fall after some time and give equality over a range of thickness of filtering aluminium in the final curve.

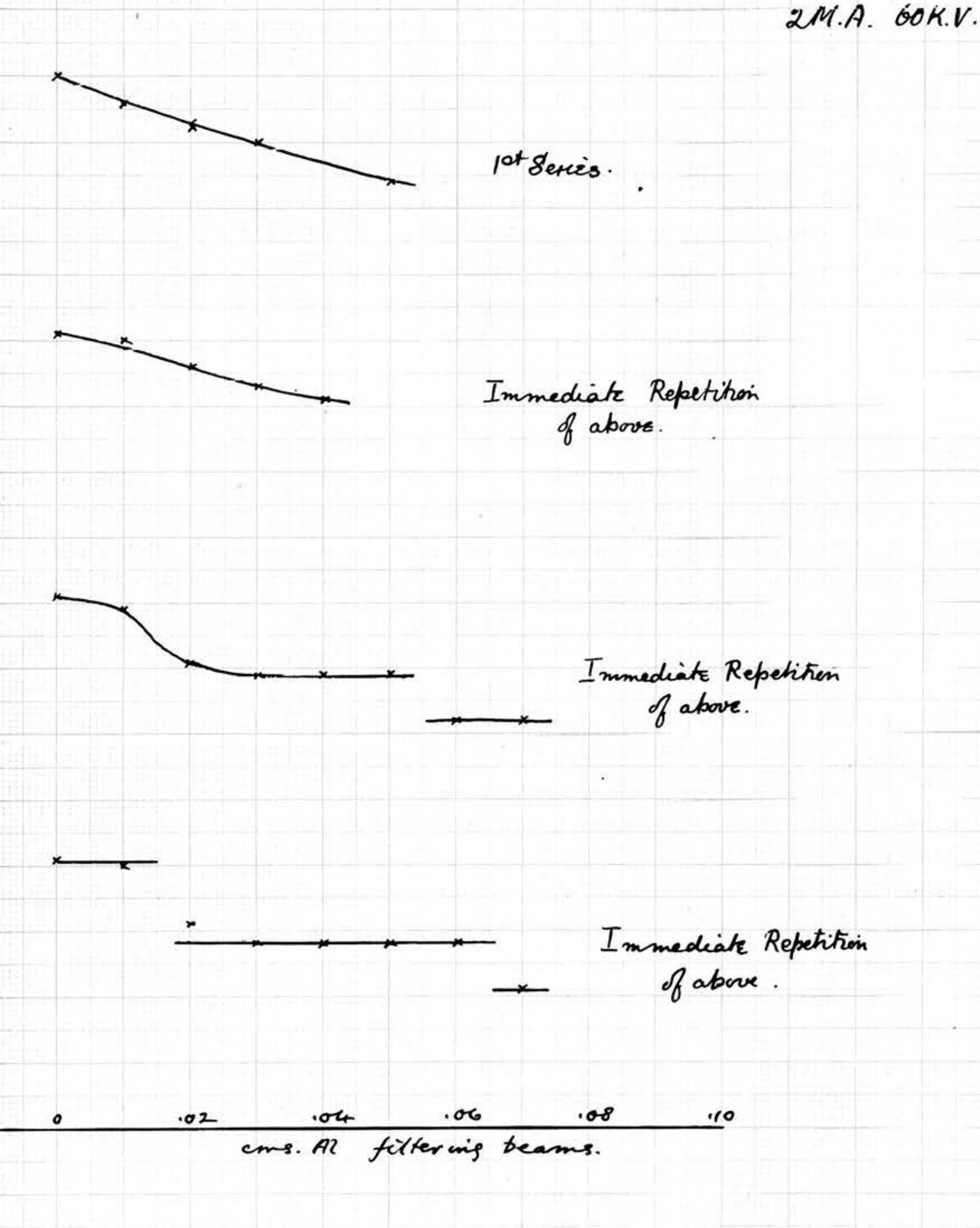
12 mms. Carbon.

1·3 MA. 60K.V.



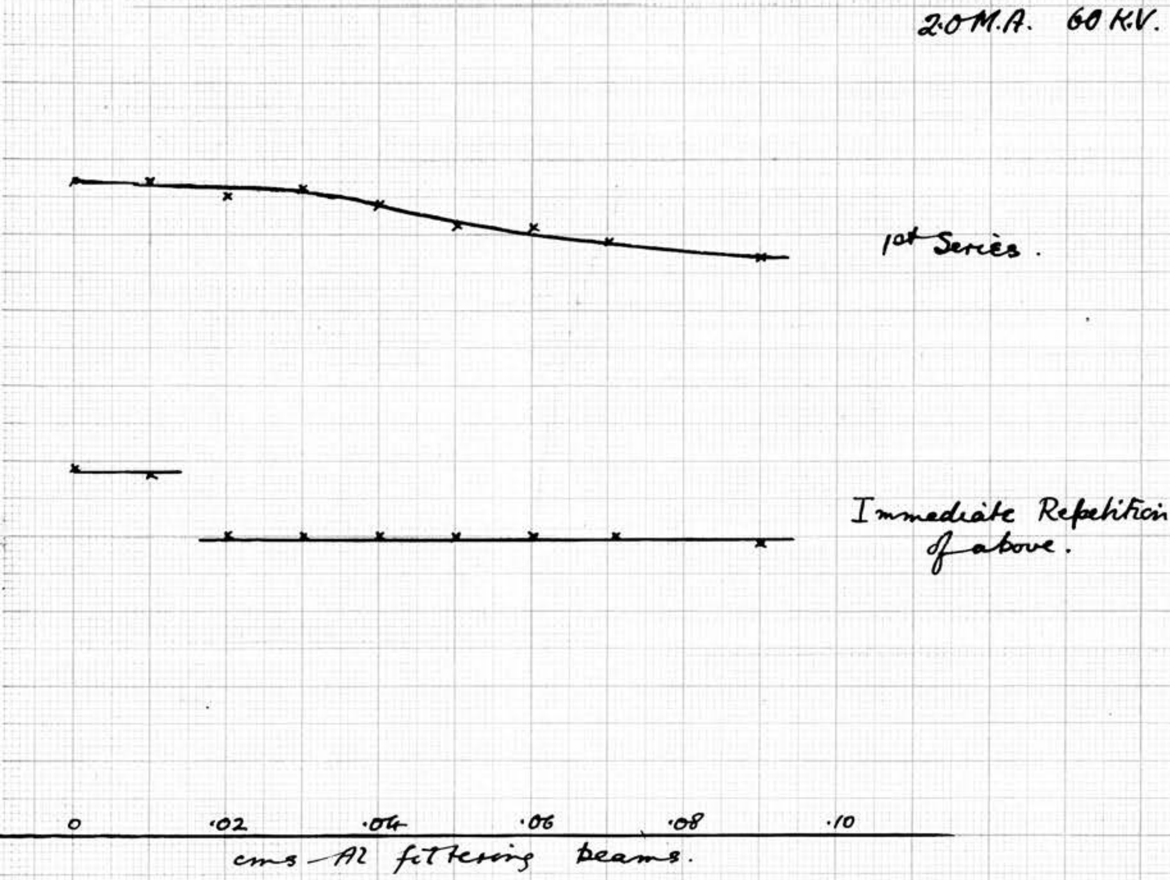
Although there are rather few points on the slope drawn above it seems possible that development may have taken place in the short time necessary for the three or four initial observations.

19 mms. Paraffin Wax



Development takes place from continuous slope to discontinuities.

19 mms. Paraffin Wax



Development of change occurs from slope to discontinuities on repetition.

C U R V E S

from

E X P E R I M E N T S

in which

ATTEMPTS WERE MADE TO DISPLACE

THE POSITION

OF

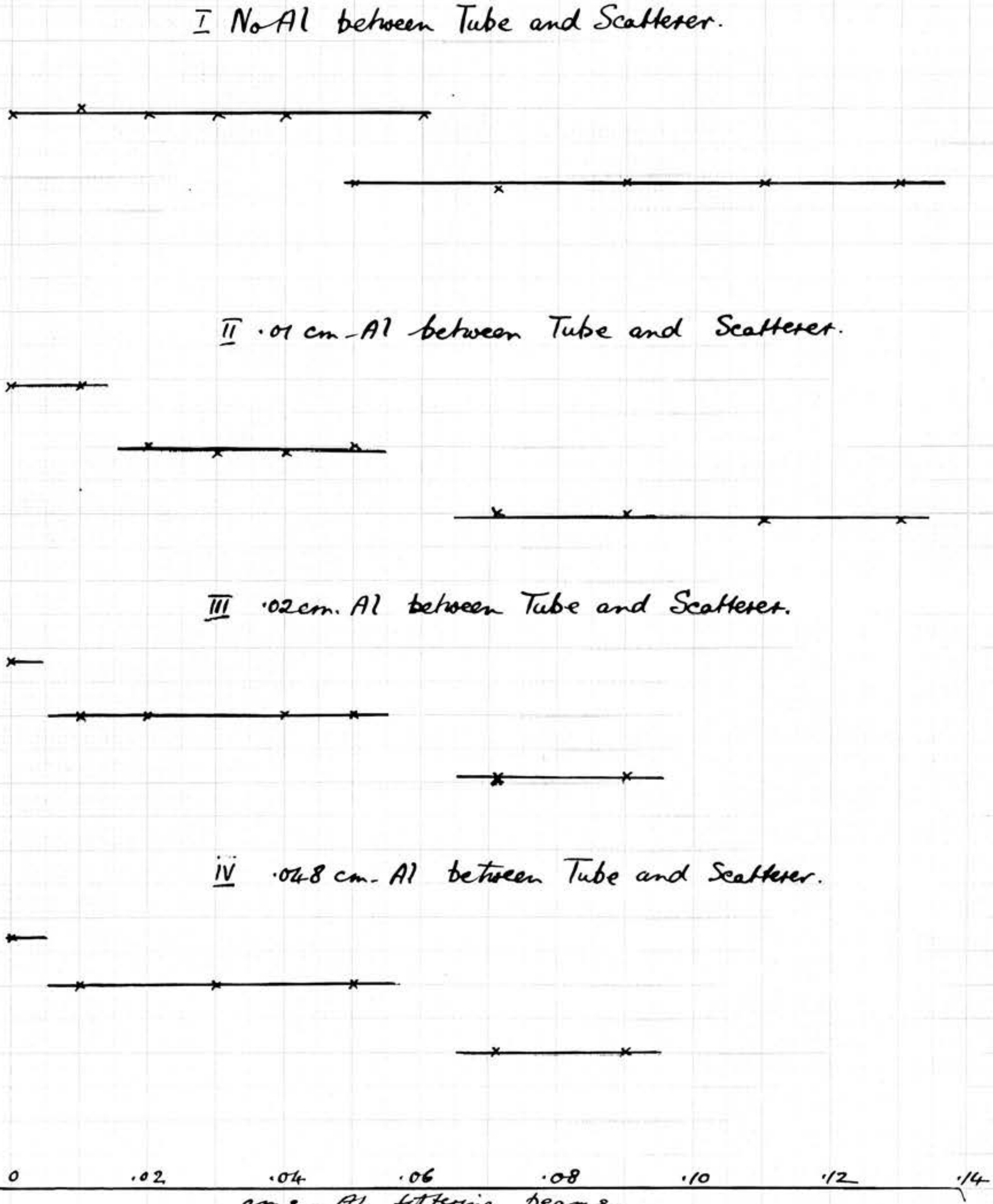
THE J-DISCONTINUITIES,

with a curve from an experiment
in which a sheet of Silver was
added to the scatterer.

---

19 mms. Paraffin Wax

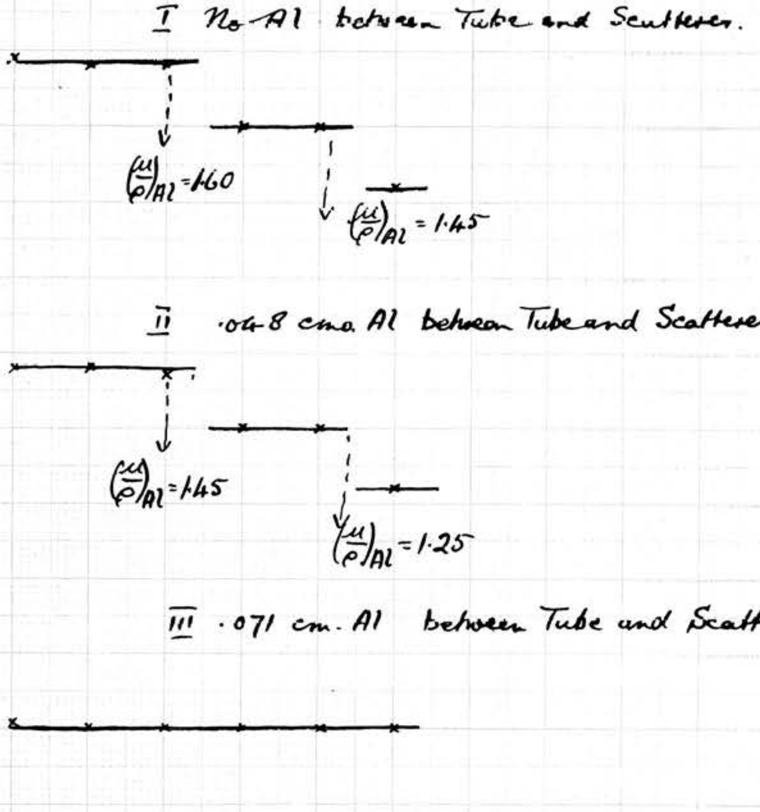
1·5 M.A. 60 K.V.



There is a difference between the beginning of curve I and that of curves II, III and IV but otherwise there is no essential difference between the results as shown by the curves above.

19 mms. Paraffin Wax.

1.5 M.A. 60 K.V.

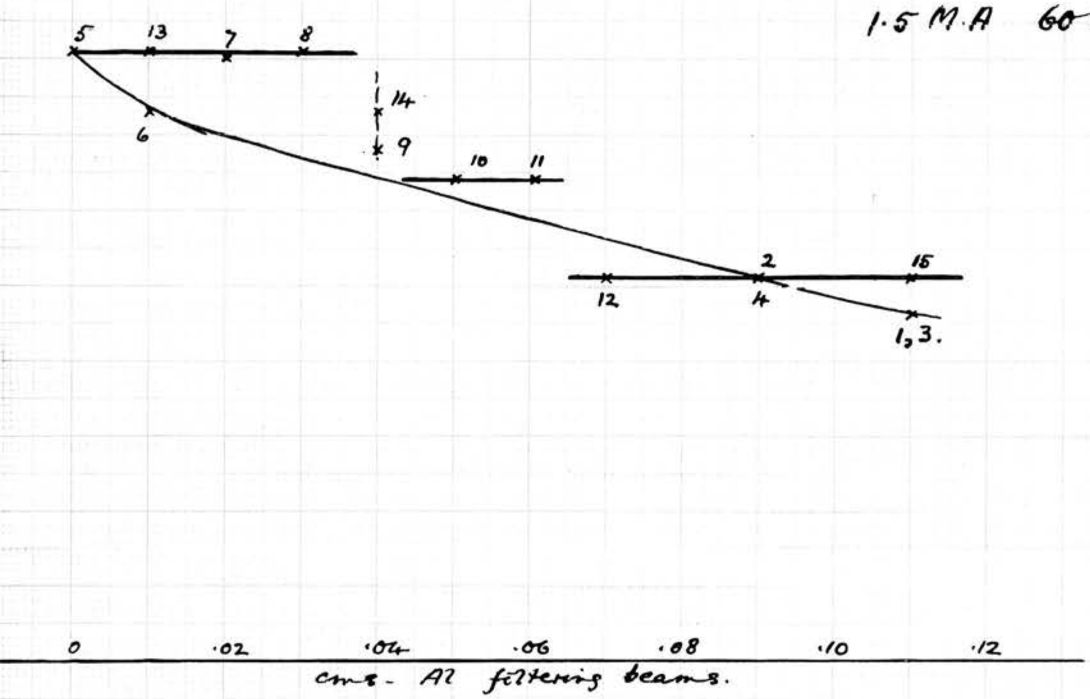


Curves I and II are similar; the absorption coefficients at the points of discontinuity move towards the left i.e. in the direction of decreasing thickness of Al filters, but the values of the ratios S/p remain same. Curve III shows the ratio S/p remaining constant throughout.

19 mms. Paraffin Wax with sheet of Silver Foil attached.

Silver ·00216 cm. thick.

1·5 M.A 60 K.V.



First few observations indicate a smooth slope for the filtering curve, but later observations show the discontinuities.

C U R V E S

showing

THE J-DISCONTINUITIES

IN FILTERING EXPERIMENTS

together
with

CURVES SHOWING

DISCONTINUITIES

IN THE PROGRESSIVE ABSORPTION

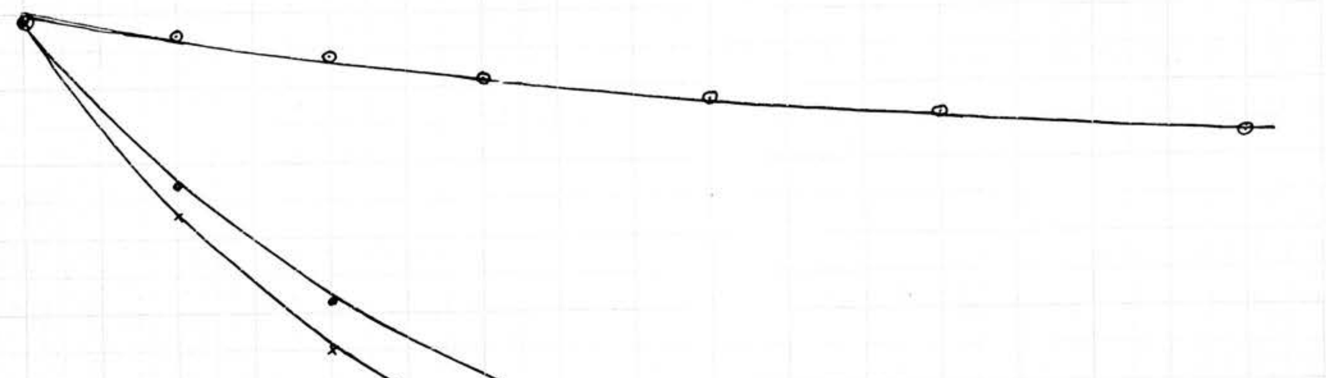
OF THE PRIMARY AND SECONDARY

RADIATIONS.

19mms Paraffin Wax.

2M.A. 60K.V.

⊙ represents ratio S'/P'
× represents ratio S'/P
• represents ratio P'/S from formula
$$P'/S = (S'/P)^2 \div S'/P'$$

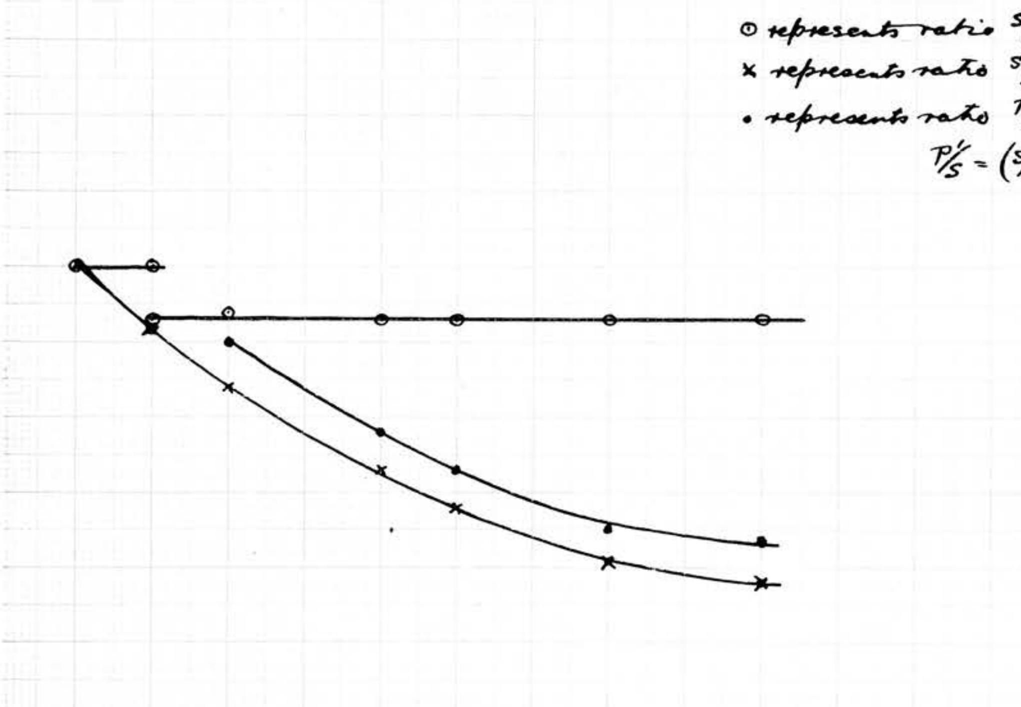


cms Al filtering beams.

The filtering curve is a slope and the curves, for absorption of the primary and secondary beams separately, verify this.
The ratio P'/S is always greater than the corresponding ratio S'/P, and the ratios P'/S and S'/P do not decrease at the same rate.

98 sheets Paper.

2M.A. 60 K.V.

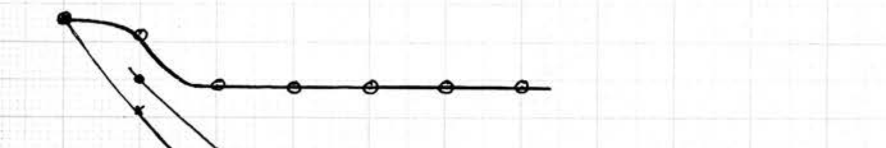


At and after the point of discontinuity in S'/P', the value of the ratio P'/S is greater than the corresponding value of the ratio S'/P, and both ratios decrease at the same rate. Up to the point of discontinuity the ratios P'/S and S'/P have the same value.

6 mms. Carbon.

1·3 M.A. 60 K.V.

⊙ represents ratio S'/P'
× represents ratio S/P
• represents ratio P'/S from formula $P'/S = (S/P)^2 \div S/P'$



At the point of discontinuity the values of P'/S become greater than the corresponding values of S/P.

After a few observations following the discontinuity, the ratios S/P and P'/S seem to fall away (decrease) at the same rate.

The discontinuity occurs too early to allow of any definite statement.

6 mms. Carbon.

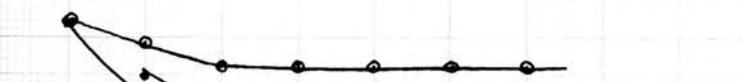
1·3 M.A. 60 K.V.

⊙ represents ratio S'/P'

× represents ratio S'/P

• represents ratio P'/S from formula

$$P'/S = (S'/P)^2 \div S'/P'$$



Although there is no abrupt discontinuity, the constancy of the ratio S'/P' over a range of thickness of Al filters is verified by the values of the ratios S'/P and P'/S decreasing at the same rate.

19 mms. Paraffin Wax

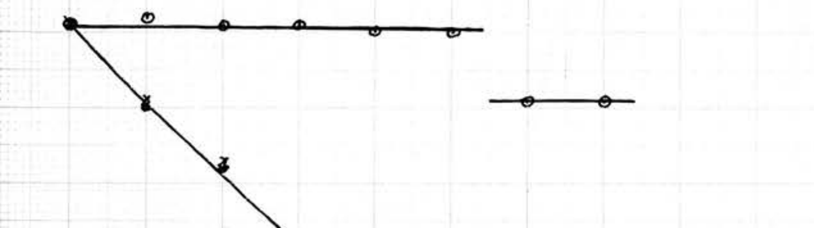
1·3 M.A. 60K.V.

○ represents ratio S'/P'

× represents ratio S'/P

• represents ratio P'/S from formula

$$P'/S = (S'/P)^2 \div S'/P'$$



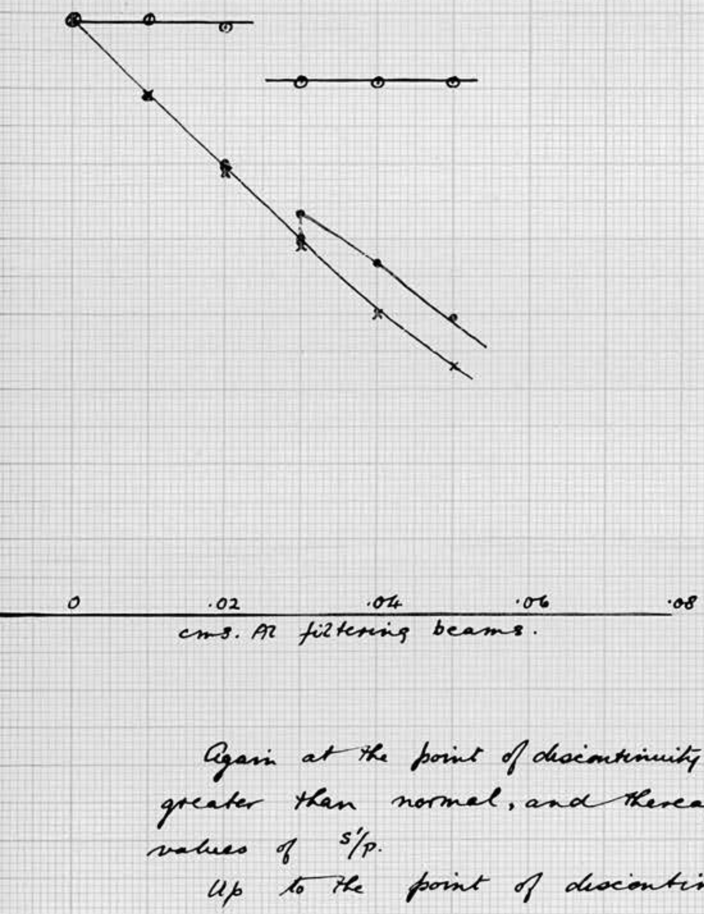
Up to the point of discontinuity of S'/P', the constancy of S'/P' is verified by the values of the ratios S'/P and P'/S, for a given thickness of Al filter, being equal. At the point of discontinuity and after it, the ratio S'/P decreases at the normal rate, but the ratio P'/S increases in value above the normal and thereafter decreases at the same rate as the ratio S'/P.

19 mms. Paraffin Wax.

2M.A. 60K.V.

○ represents ratio S/P'
× represents ratio S/P
• represents ratio P/S from formula,

$$P/S = (S/P)^2 \div S/P'$$



Again at the point of discontinuity of S/P', the values of the ratio P/S become greater than normal, and thereafter decrease at the same rate as the values of S/P.

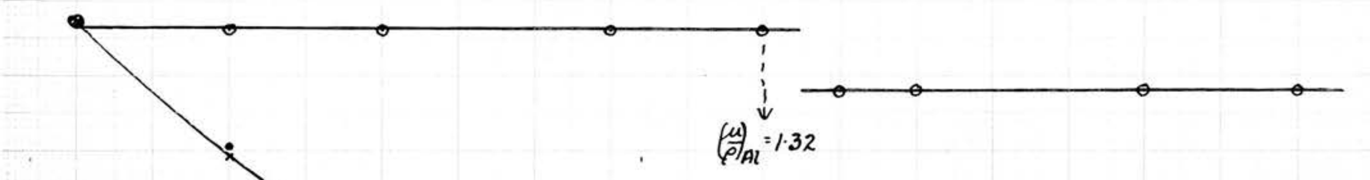
Up to the point of discontinuity, the values of these ratios S/P and P/S, for a given thickness of Al. filters, are equal verifying the constant value observed for the ratio S/P' over the same range of thickness of filtering Aluminium.

19 mms. Paraffin Wax.

1·5 M.A. 60 K.V.

⊙ represents ratio S'/p'
× represents ratio S'/p
• represents ratio P'/s from formula,

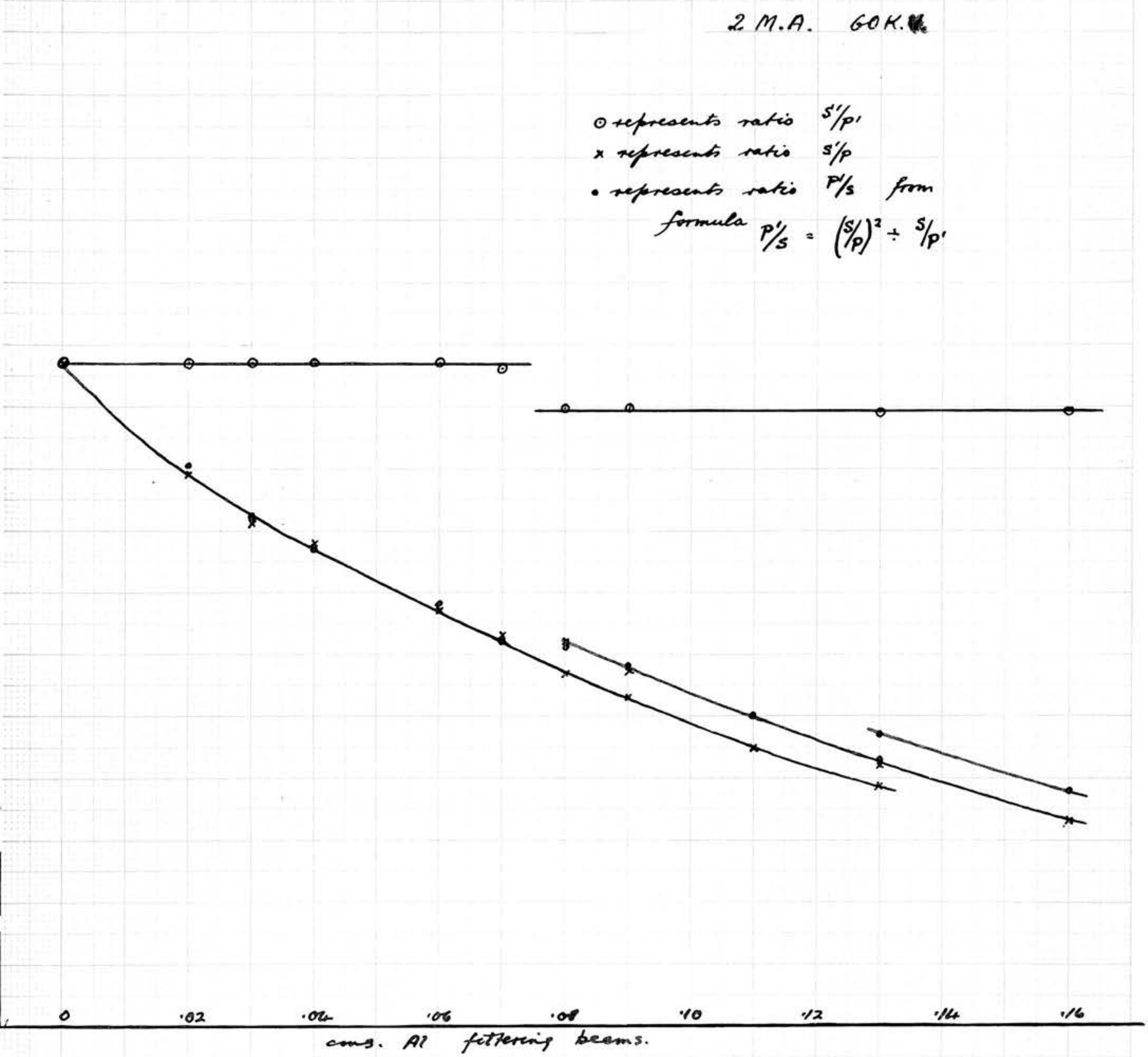
$$P'/s = (S'/p)^2 \div S'/p'$$



At the point of discontinuity, the values of P'/s become greater than normally expected; the values of S'/p decrease in the normal way, and after the discontinuity the values of P'/s and S'/p decrease at the same rate.

Up to the point of discontinuity, the values of P'/s and S'/p for the same thickness of filtering Aluminium are equal thus verifying the observed constancy of the ratio S'/p' with increasing thickness of filtering Aluminium.

19 mms. Paraffin Wax

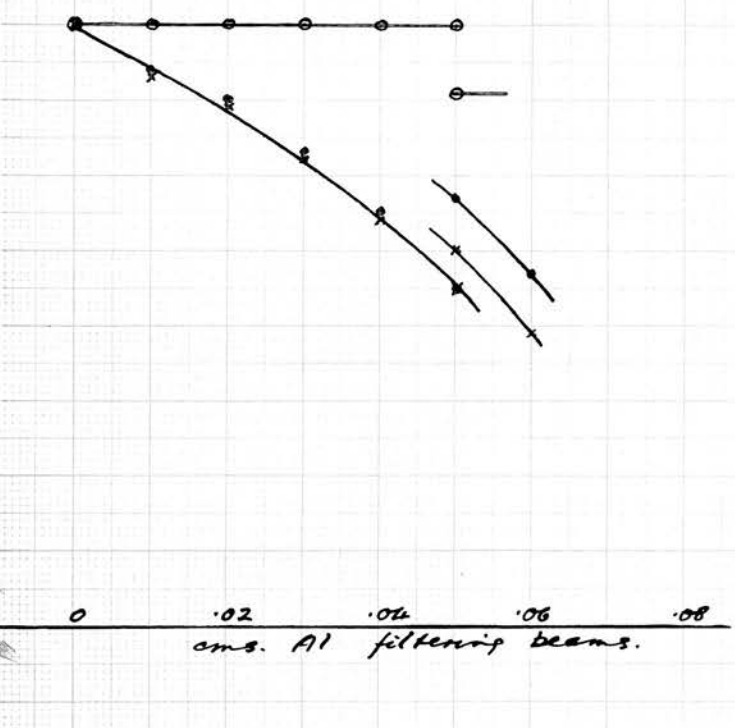


Up to the point of discontinuity, the values of the ratio P'/S are equal to the corresponding values of the ratio S/P. At the point of discontinuity and after it the values of the ratio P'/S increase to a value greater than normally expected, while the ratio S/P decreases in the usual way. Both decrease at the same rate.

19 mms. Paraffin Wax.

2M.A. 60 K.V

o represents ratio S'/P'
x represents ratio S'/P
• represents ratio P'/S from formula $P'/S = (S'/P)^2 \div S'/P'$

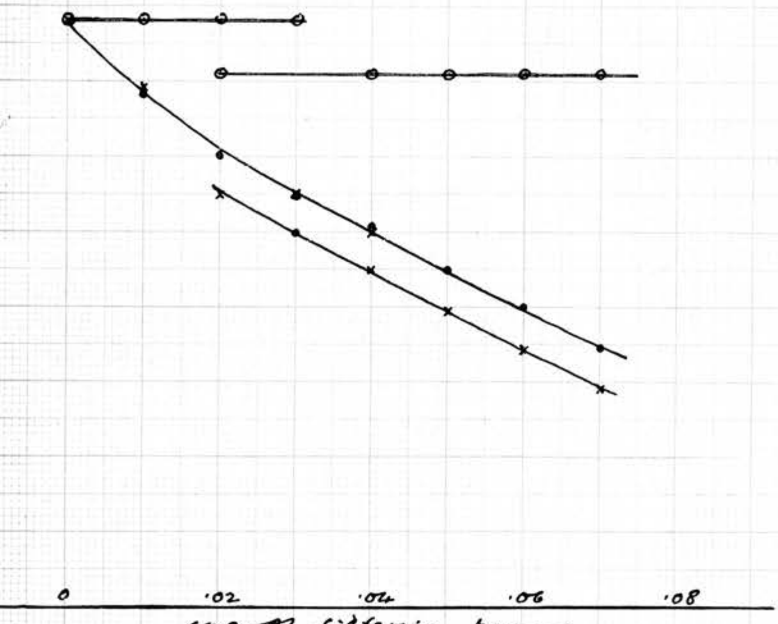


In this case, up to the point of discontinuity, the constancy of the observed ratio S'/P' is verified by the fact that the corresponding values of P'/S and S'/P are equal. At the point of discontinuity, the values of P'/S and S'/P become discontinuously greater than normally expected and thereafter decrease at the same rate, the values of P'/S always being greater than the corresponding value of S'/P.

19 mms. Paraffin Wax.

1 M.A. 60 K.V.

⊙ represents ratio S/P'
× represents ratio S/P
• represents ratio P'/S from formula $P'/S = (S/P)^2 \div S/P'$



Again, the corresponding values of P/S and S/P are equal up to the point of discontinuity, where, in this case, the values of S/P decrease more than normally expected and the ratios P/S decrease in the normal way. Both decrease at the same rate.

19 mms. Paraffin Wax

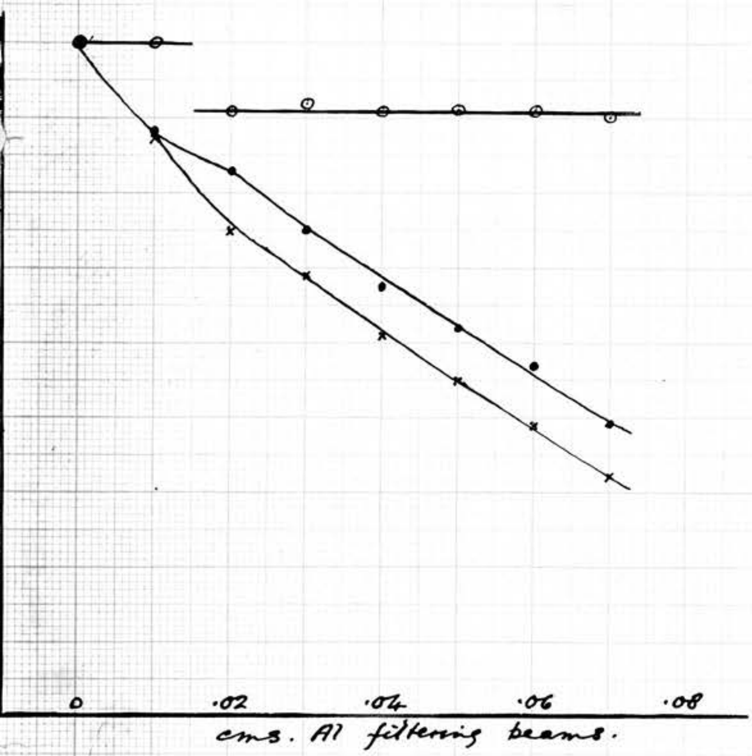
2M.A. 60 K.V.

⊙ represents ratio S'/P'

× represents ratio S'/P

• represents ratio P'/S from formula

$$P'/S = (S'/P)^2 \div S'/P'$$



It is difficult to state whether, at the discontinuity, the change is due to an increase in the values of P'/S or a decrease in the values of S'/P or to both these changes. Certainly the ratios separate and decrease at the same rate after the point of discontinuity.